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CONTENTS

THE SELECTION OF BURMA BEANS (PHASEOLUS LUNATUS) FOR LOW PRUSSIC ACID CONTENT.

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I. INTRODUCTORY.

The methods of estimation of HCN utilized in this paper were briefly as follows :—

1. *Auto-enzyme HCN.*[1] By this term is signified the amount of HCN which could be liberated at any given time by the enzymes present in the seeds of Burma beans by crushing these and leaving in contact with water in a closed flask for twenty-four hours at room temperature. After this time had elapsed the beans were steam distilled and the HCN absorbed in $N.NaHCO_3$ solution. 300 c.c. of distillate were collected.
2. *Glucosidal HCN.*[2] Thirty grams of Burma beans were extracted successively with two lots of boiling water, each of 300 c.c., for one and-a-half hours for each lot. These extracts were then combined and evaporated down to about 200 c.c. after which the extract was decomposed with 100 c.c. of thirty per cent. H_2SO_4 and the HCN set free distilled off by steam at intervals during a period of six hours. The distillate was collected in $N.NaHCO_3$ solution, 300 c.c. of distillate being collected.
3. *Total HCN.*[3] To a series of flasks each containing thirty grams of freshly crushed Burma beans, increasing weights of finely ground brewers' malt were added. 300 c.c. tap water were then added to each, the flasks firmly stoppered and allowed to stand at room temperature for twenty-four hours after which the contents were steam distilled, 300 c.c. of distillate being collected in $N.NaHCO_3$ solution.

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[1] Warth, F. J. *Mem. Dept. Agri. India, Chem. Ser.*, Vol. VII, No. 1.
[2] Warth, F. J. *Ibid.*
[3] Charlton, J. *Agri. Res. Inst. Pusa, Bull.* 140.

It should be noted that the method for estimation of total HCN is described as total HCN for convenience only. It is subsequently shown that no single method of estimation of HCN yields the whole of the HCN contained by the beans.

To the distillates as collected above a quantity of N.NaOH solution equal in amount to the $N.NaHCO_3$ used for absorption was added, together with 16 c.c. of ten per cent. $FeSO_4$ solution and the HCN precipitated as prussian blue, the flasks being acidified after shaking at five minute intervals for two hours.

The attempt to eliminate prussic acid from Burma beans was confined to six strains which had been collected and grown by the previous Agricultural Chemist, Burma, Mr. F. J. Warth. These strains were named Monywa, B, G, J, K and M and comprised 131 separate plants of high yield which were almost ready for harvest when I arrived in Mandalay in January 1921. Selection work has been confined to these strains. Owing to the comparatively unfavourable conditions in Mandalay where the soil is unsuitable and the rains frequently unseasonable for this crop, mass selection only could be attempted here. For this reason a portion of sample K was grown at Tatkon on a fertile loam with better rainfall in 1921-22 and the results of this selection compared with similar ones grown at Mandalay in the same year. Yields were greatly in favour of Tatkon as a breeding place and hence after the season 1921-22 all selection work was transferred to Tatkon and the method of single plant selection adopted for all strains.

Results of single plant selection were worked out on the statistical basis for sample K in 1921-22 and for the other strains in 1922-23. For all successive crops statistical results were worked out. Analytical data where available are given for previous years' mass selection, but these results are to be regarded as of general interest only.

Selections B and J disappeared before 1924-25, partly because results from these strains were not so promising as the others and partly because they were more adversely affected by weather conditions than other strains.

Statistical results were all based on a special method of estimation of prussic acid, *viz.*, as total HCN by addition of brewers' malt. Prior results were obtained by extraction of the cyanogenetic glucoside with hot water followed by acid hydrolysis, *i.e.*, glucosidal HCN was estimated. With newly harvested beans the former method gives higher results and is therefore to be preferred as a basis for selection work. Further, since it is only possible to obtain a prussian blue reaction from 0·0003 grm. HCN in a bulk of 400 c.c. of water, when 30 grams of Burma beans were used for estimation a *nil* result merely means that HCN present was less than 0·0010 grm. per cent. In 1922-23 when a very good crop was obtained, fifty grams of seed were used for analysis in the case of strain K and hence a *nil* result would have signified that less than 0·0006 grm. per cent. was present. No *nil* result has ever been obtained when using brewers' malt to liberate HCN although several such cases occurred when extraction of the cyanogenetic glucoside by hot water followed by acid hydrolysis was utilized to liberate HCN. Such

a *nil* result is therefore to be regarded as indicating that less than 0·0010 per cent. glucosidal HCN was present since thirty grams of seed were used for these estimations and that the acid hydrolysis method is not capable of liberating the whole of the HCN in newly harvested Burma beans.

It is to be expected that results of selection will depend to some extent on the method of estimation of HCN. The author is of opinion that the best method would be that giving the maximum amount of HCN since this represents the potential danger of a variety. Of all methods tried, the one adopted, *viz.*, addition of brewers' malt to liberate HCN, gave highest results with newly harvested beans and hence was the best available method. The absolute maximum content of prussic acid cannot be stated as this is a variable quantity depending upon age of the sample and also upon the method of storage.[1]

The proportion of brewers' malt added to liberate the HCN was the smallest amount required to give maximum yield of HCN. The amount necessary was determined individually for each strain from a bulk sample collected separately from plants giving a yield of seed less than thirty grams. The seeds from such plants could not be subjected to separate analysis.

Season 1923-24 was particularly unfavourable to the crop. Owing to unseasonable rains, sowing was delayed and yields suffered by continued growth into the hot weather. The figures obtained for *standard deviation* and *coefficient of variability* were therefore somewhat a-typical. The *probable errors* of the determinations were high and too much importance should not be attached to these results. The values for the *means* were, however, substantially correct, because it was possible to verify these from results of analysis of bulk samples from plants giving smaller yields of seed than thirty grams. Good checks were obtained in all cases.

II. RESULTS OF SELECTION FOR LOW HCN CONTENT.

1. *Sample Monywa* 7. The actual values obtained are given in Table I.

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[1] *Annual Report of the Agricultural Chemist, Burma, for the year ending* 30th June 1923.

TABLE I.

Monywa 7.

1918-19	1919-20	1920-21	1921-22	1922-23	1923-24	1924-25
?	?	0·0052	*nil* → (Mass)	→ A142 (105) (*a*) 0·0041 ± 0·000190 (*b*) 0·002891 ± 0·000135 (*c*) 70·5 ± 4·63 →	A142/82 (23) (*a*) 0·0062 ± 0·000170 (*b*) 0·001207 ± 0·000120 (*c*) 19·47 ± 2·008 →	A142/82/14 (18) (*a*) 0·0050 ± 0·000120 (*b*) 0·000752 ± 0·000085 (*c*) 15·05 ± 1·73
						→ A142/42 (100) (*a*) 0·0043 ± 0·000064 (*b*) 0·000956 ± 0·000046 (*c*) 22·24 ± 1·112
						→ A142/82 (Bulk sample) (99) (*a*) 0·0035 ± 0·000040 (*b*) 0·000588 ± 0·000028 (*c*) 16·80 ± 0·83

Arrows indicate course of selection.
Numbers in brackets below the names of strains indicate the number of individual plants analyzed.
(*a*) = mean per cent. HCN.
(*b*) = standard deviation.
(*c*) = coefficient of variability.

In season 1921-22 a mass selection yielded beans containing *nil* per cent. HCN, the HCN being determined by hot water extraction of the glucoside followed by acid hydrolysis. From 1922-23 to 1924-25 the mean HCN content was as follows :— 0·0041 per cent., 0·0062 per cent. and 0·0050 per cent. The arrows in the diagram indicate the course of selection pursued. From these it is seen that—

(*a*) A sample stored over the season 1923-24, *viz.*, A142/42, gave a lower mean HCN per cent. than the sample A142/84/14 which had been subjected to continuous selection year by year.

(*b*) A bulk sample from the 1923-24 crop, A142/82, gave a lower mean HCN per cent. than the sample A142/82/14 which had been continuously selected without a break.

2. *Sample G.* The direct selection of this strain was not continued in 1924-25 as the best individual plants from the 1923-24 crop left little seed and better strains were available. A bulk sample from the 1923-24 crop, A207/22, and a single plant selection from the 1922-23 crop were grown however, and the result of these selections may be seen in Table II.

TABLE II.

Sample G.

1918-19	1919-20	1920-21	1921-22	1922-23	1923-24	1924-25
nil	?	0·0038	G49/2 *nil* →	G49/2-A207 (32) (*a*) $0·0029 \pm 0·000044$ (*b*) $0·000350 \pm 0·000030$ (*c*) $12·48 \pm 1·07$ →	G49/2-A207 (15) (*a*) $0·0071 \pm 0·000290$ (*b*) $0·001666 \pm 0·000205$ (*c*) $23·46 \pm 3·05$ →	Not reselected in 1924-25 as better samples were available.
				→		A207/10 (100) (*a*) $0·0048 \pm 0·000064$ (*b*) $0·000951 \pm 0·000045$ (*c*) $19·82 \pm 0·98$
					→	A207/22 (Bulk sample) (100) (*a*) $0·0045 \pm 0·000063$ (*b*) $0·000940 \pm 0·000045$ (*c*) $20·89 \pm 1·04$

Arrows indicate course of selection.
Numbers in brackets below the names of strains indicate the number of individual plants analyzed.
(*a*) = mean per cent. HCN.
(*b*) = standard deviation.
(*c*) = coefficient of variability.

The mean HCN per cent. in 1924-25 samples, A207/10 and A207/22, were both considerably lower than the value obtained from sample G49/2-A207 in 1923-24.

3. *Sample K.* Statistical results for this sample are available for four years but are complete only in the two cases of 1924-25 samples K113/28/25 and K159/84/15. Results are given in Table III

Table III.

Sample K.

1918-19	1919-20	1920-21	1921-22	1922-23	1923-24	1924-25
				K102 (33) (a) 0·0023 ± 0·000037 (b) 0·000311 ± 0·000026 (c) 13·52 ± 1·14	K102/7 (16) (a) 0·0059 ± 0·000203 (b) 0·001205 ± 0·000144 (c) 20·42 ± 2·534	K102/25 (100) (a) 0·0034 ± 0·000039 (b) 0·000581 ± 0·000028 (c) 17·09 ± 0·84
					(80)	K102/7 (Bulk) (80) (a) 0·0036 ± 0·000040 (b) 0·000526 ± 0·000028 (c) 14·61 ± 0·80
				K109 (72) (a) 0·0021 ± 0·000030 (b) 0·000378 ± 0·000021 (c) 17·99 ± 1·04	K109/50 (3) (a) 0·0059 ± 0·000164 (b) 0·000420 ± 0·000116 (c) 7·12 ± 1·96	K109/43 (81) (a) 0·0033 ± 0·000047 (b) 0·000630 ± 0·000033 (c) 19·10 ± 1·05
						K109/50 (Bulk) (96) (a) 0·0042 ± 0·000050 (b) 0·000711 ± 0·000035 (c) 16·92 ± 0·85
				K113 (104) (a) 0·0032 ± 0·000049 (b) 0·000726 ± 0·000034 (c) 22·69 ± 1·11	K113/28 (6) (a) 0·0052 ± 0·000159 (b) 0·000577 ± 0·000112 (c) 11·10 ± 2·19	K113/28/25 (26) (a) 0·0036 ± 0·000058 (b) 0·000439 ± 0·000041 (c) 12·21 ± 1·16
						K113/22 (51) (a) 0·0031 ± 0·000034 (b) 0·000359 ± 0·000024 (c) 11·59 ± 0·78
						K113/28 (Bulk) (72) (a) 0·0039 ± 0·000048 (b) 0·000604 ± 0·000034 (c) 15·49 ± 0·89
0·0003	?	0·0026 (Mass)	K (a) 0·0034 + 0·000018 (b) 0·000693 + 0·000018 (c) 20·21 + 0·39	K159 (105) (a) 0·0027 ± 0·000041 (b) 0·000625 ± 0·000029 (c) 23·15 ± 1·13	K159/84 (15) (a) 0·0056 ± 0·000300 (b) 0·001725 ± 0·000212 (c) 30·80 ± 4·14	K159/84/15 (7) (a) 0·0033 ± 0·000068 (b) 0·000267 ± 0·000048 (c) 8·10 ± 1·47
						K159/82 (55) (a) 0·0030 ± 0·000072 (b) 0·000788 ± 0·000051 (c) 26·26 ± 1·80
						K159/84 (Bulk) (97) (a) 0·0039 ± 0·000062 (b) 0·000900 ± 0·000044 (c) 23·07 ± 1·18
				K239 (95) (a) 0·0026 ± 0·000046 (b) 0·000650 ± 0·000032 (c) 25·01 ± 1·16	K239/84 (9) (a) 0·0059 ± 0·000112 (b) 0·000495 ± 0·000079 (c) 8·40 ± 1·34	K239/43 (69) (a) 0·0034 ± 0·000056 (b) 0·000690 ± 0·000040 (c) 20·31 ± 1·21
						K239/84 (Bulk) (97) (a) 0·0042 ± 0·000041 (b) 0·000603 ± 0·000029 (c) 14·35 ± 0·71
				K354 (97) (a) 0·0024 ± 0·000030 (b) 0·000432 ± 0·000021 (c) 18·38 ± 0·92	K354/5 (11) (a) 0·0063 ± 0·000334 (b) 0·001644 ± 0·000236 (c) 26·09 ± 4·00	K354/28 (70) (a) 0·0032 ± 0·000047 (b) 0·000584 ± 0·000033 (c) 18·25 ± 1·07
						K354/54 (Bulk) (93) (a) 0·0039 ± 0·000056 (b) 0·000801 ± 0·000040 (c) 20·51 ± 1·06
				K393 (90) (a) 0·0022 ± 0·000037 (b) 0·000518 ± 0·000026 (c) 23·53 ± 1·25	K393/84 (10) (a) 0·0061 ± 0·000291 (b) 0·001363 ± 0·000206 (c) 22·34 ± 3·53	K393/51 (91) (a) 0·0031 ± 0·000027 (b) 0·000380 ± 0·000019 (c) 12·24 ± 0·62
						K393/84 (Bulk) 99 (a) 0·0041 ± 0·000056 (b) 0·000825 ± 0·000040 (c) 20·13 ± 1·00

Arrows indicate course of selection.
Numbers in brackets below the names of strains indicate the number of individual plants analyzed.
(a) = mean per cent. HCN.
(b) = standard deviation.
(c) = coefficient of variability.

The mean HCN per cent. in the case of samples K113/28/25 and K159/84/15 from 1921-22 until 1924-25 are as follows :—

K113/28/25	0·0034, 0·0032, 0·0052, 0·0036.
K159/84/15	0·0034, 0·0027, 0·0056, 0·0033.

Obviously, therefore, the effect of a bad season in 1923-24 has rendered four years' rigorous selection entirely ineffective since the mean per cent. HCN in 1924-25 is practically the same as in 1921-22.

Although results for other strains within this sample K are incomplete they strongly support the same fact, *viz.*, that all varieties in 1924-25 whether continuously selected from single plants, whether stored over the bad season 1923-24 or reselected from bulk samples from 1923-24 crop show no definite reduction of mean HCN content in 1924-25 as compared with 1921-22.

Further, sample K113/22 which is a single plant selection stored in 1923-24 gave a lower mean HCN per cent. in 1924-25 than K113/28/25 which was continuously selected without a break. Similarly sample K159/82 which was also a single plant selection stored in 1923-24 gave a lower mean HCN per cent. in 1924-25 than sample K159/84/15 which was continuously selected without a break.

In the case of the other samples K102, K109, K239, K354 and K393 no single plant selections could be made from the 1923-24 crop. Bulk selections were made, however, and the best available individual plants from the 1922-23 crop were sown and harvested in 1924-25. Without exception, these show a marked improvement in mean HCN content compared with the 1923-24 crop, but none can be said to be substantially better than the original selection K in 1921-22.

4. *Sample M.* The original beans from this selection contained 0·0003 per cent. glucosidal HCN in 1918-19. By 1922-23 when results were put on the statistical basis and individual plant analysis made, three sub-strains had resulted :—A270, A278 and A297. The progress of selection work with these is shown in Table IV.

Table IV.

Sample M.

1918-19	1919-20	1920-21	1921-22	1922-23		1923-24		1924-25	
		0·0023	M111/1 (Single plant) 0·0017	A270 (37)	(a) 0·0023±0·000034 (b) 0·000311±0·000024 (c) 13·23±1·05	A270/37 (9)	(a) 0·0052±0·000115 (b) 0·000510±0·000081 (c) 9·81±1·57	A270/37/15 (30)	(a) 0·0045±0·000075 (b) 0·000609±0·000053 (c) 13·53±1·20
								A270/37/16 (31)	(a) 0·0041±0·000081 (b) 0·000672±0·000058 (c) 16·38±1·44
								A270/37/26 (12)	(a) 0·0037±0·000106 (b) 0·000542±0·000075 (c) 14·66±2·06
								A270/20 (100)	(a) 0·0038±0·000048 (b) 0·000708±0·000034 (c) 18·63±0·92
								A270/37 (Bulk sample) (100)	(a) 0·0035±0·000045 (b) 0·000673±0·000032 (c) 19·23±0·95
0·0003	?	0·0029	M115 (Mass) 0·0023	A278 (95)	(a) 0·0023±0·000029 (b) 0·000425±0·000022 (c) 18·73±1·01	A278/61 (7)	(a) 0·0052±0·000089 (b) 0·000348±0·000063 (c) 6·70±1·21	A278/67 (81)	(a) 0·0036±0·000050 (b) 0·000674±0·000036 (c) 18·69±1·02
		0·0023	M127 (Mass) 0·0023	A297 (103)	(a) 0·0023±0·000030 (b) 0·000456±0·000022 (c) 19·83±0·97	A297/1 (5)	(a) 0·0051±0·000224 (b) 0·000743±0·000159 (c) 14·57±3·20	A278/61 (Bulk sample) (91)	(a) 0·0040±0·000058 (b) 0·000822±0·000041 (c) 20·54±1·07
								A297/56 (97)	(a) 0·0034±0·000035 (b) 0·000494±0·000024 (c) 14·54±0·72
								A297/1 (Bulk sample) (80)	(a) 0·0035±0·000040 (b) 0·000529±0·000028 (c) 15·11±0·82

Arrows indicate course of selection.
Numbers in brackets below the names of strains indicate the number of individual plants analysed.
(a) = mean per cent. HCN.
(b) = standard deviation.
(c) = coefficient of variability.

Continuous selection was only possible with the first named and seed from the three best plants of 1923-24 were grown in 1924-25, *viz.*, A270/37/15, A270/37/16 and A270/37/26. Although each of these shows a reduction in mean HCN per cent. compared with the bad season 1923-24, all contain a much greater mean per cent. HCN than in 1922-23. Sample A270/20, a single plant selection stored in 1923-24, has given practically as low a mean HCN per cent. in 1924-25 as the best direct continuous selection A270/37/26 and lower than the two other continuously selected specimens.

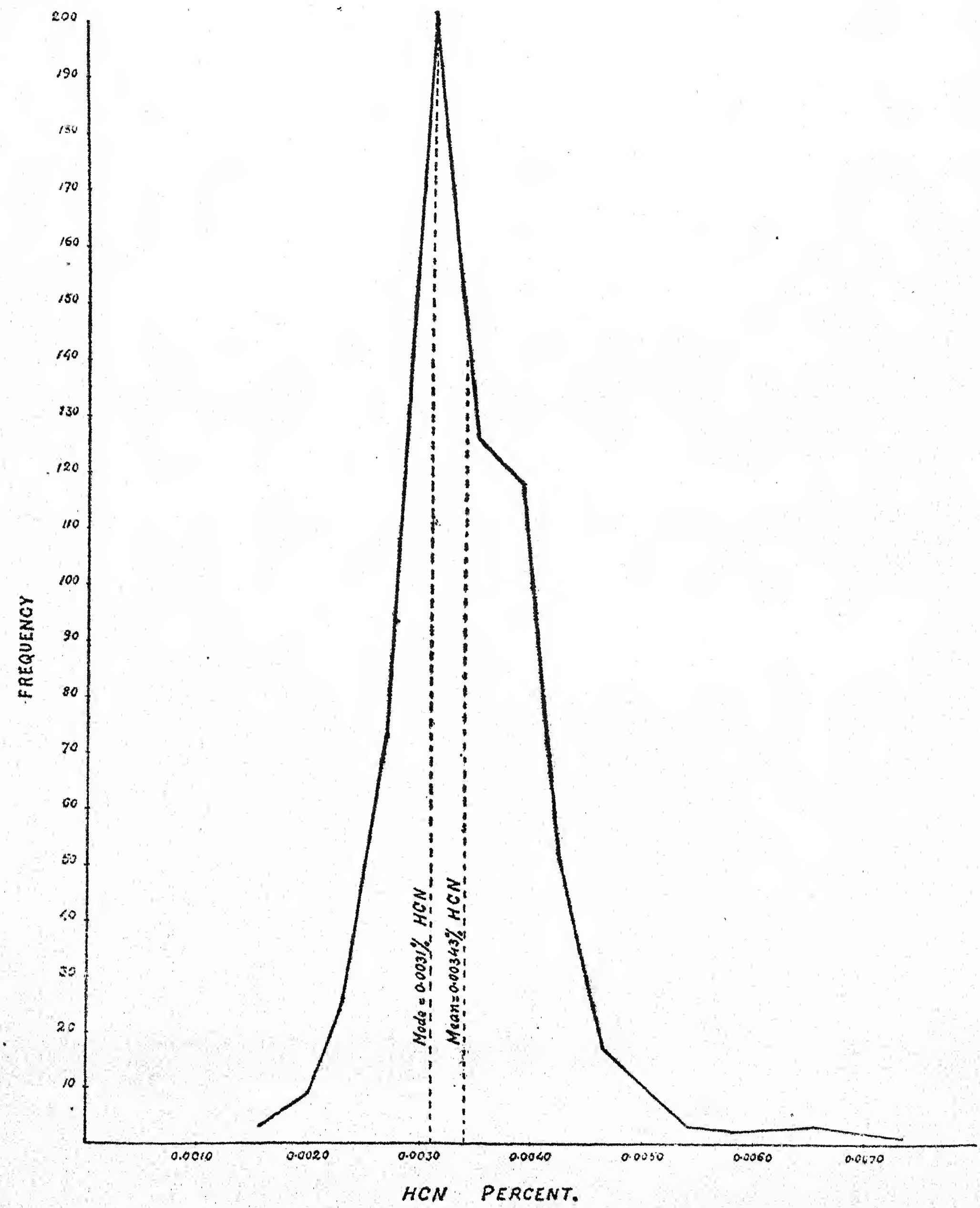
Again in the case of strains from A278 and A297, single plant selections A278/67 and A297/56 compare favourably with the 1923-24 crop but unfavourably with the starting material of 1922-23. The same remarks apply to bulk samples from the 1923-24 crop, *viz.*, A278/61 and A297/1.

III. DISCUSSION OF RESULTS.

The average values of standard deviation and coefficient of variability are 0·00073 and 18·5 per cent. respectively. These values are arrived at from the analysis of fifty-five different strains and hence considerable value is attached to these figures. In certain cases where the numbe of individual plants of a given strain was very small, say twenty or less, the values obtained differed considerably from the above. This is to be put down to the small number examined. In one case, however, Monywa A142, in 1922-23, a great divergence occurred and since 105 separate plants were analyzed to obtain the values for standard deviation and coefficient of variability, it is probable that this strain was not pure at that time. In this connection, it may be stated that the distribution curve is normal when a sufficient number of plants has been analyzed for HCN, *e.g.*, sample K in 1921-22. This distribution curve is shown in Figure 1.

FIGURE. 1

Distribution Curve for HCN in Burma Beans (K in 1921-22)



Reference to analysis of sample K in Table III shows that yearly analyses are complete only in the case of K113/28/25 and K159/84/15. These in 1924-25 have a mean content of HCN of 0·0036 and 0·0033 per cent. respectively, whereas in 1921-22 the parent sample contained only 0·0034 per cent. HCN. Since the coefficient of variability is approximately 20 per cent., in the case of sample K we should have the following with rigorous selection for low HCN content :—

	Per cent. HCN (mean).
1921-22	0·0034
1922-23	0·0027
1923-24	0·0022
1924-25	0·0017

Actually, the most favourable figures in the case of K159/84/15 are as follows :—

	Per cent. HCN (mean).
1921-22	0·0034
1922-23	0·0027
1923-24	0·0056
1924-25	0·0033

Hence environmental factors have entirely neutralized the effect of selection for low HCN content.

During the unfavourable season 1923-24 certain of the previous years' selections were stored under ideal conditions in the laboratory at Mandalay, *i.e.*, these beans were not in any way subjected to the adverse conditions suffered by the 1923-24 crop. It is well known that storage for one year does not adversely affect *pèbyugale* (Burma beans), the germination capacity, yield, etc., remaining unaffected, provided that storage is carried out under good conditions. It is therefore to be expected that these stored seeds would compare favourably with strains subjected to continuous selection. The values obtained have been extracted from Tables I-IV and are given in Table V.

TABLE V.

Mean per cent. content of prussic acid in 1924-25 crop.

Strain		Beans stored in 1923-24	Continuously selected beans
M	111/1	0·0038	(*a*) 0·0045 (*b*) 0·0041 (*c*) 0·0037
Monywa 7		0·0043	0·0050
K	K113	0·0031	0·0036
K	K159	0·0030	0·0033

In the case of strain M one of the three substrains in 1924-25 shows a difference of 0·0001 per cent. HCN in favour of beans continuously selected. This substrain consisted of twelve plants only and the difference of 0·0001 per cent. HCN cannot therefore be regarded as significant. In all other cases, the stored beans gave a lower HCN per cent. in 1924-25 than beans continuously selected. This may be regarded as strong supporting evidence that environmental factors may neutralize the selection of *pèbyugale* for low HCN content.

So few individual plants were available for direct selection in 1923-24 and 1924-25 that it may be urged that the conclusion arrived at in the previous paragraph is invalid. Supporting evidence was obtained, however, by bulking the plants giving less than thirty grams of seed from the 1923-24 crop, these beans being grown in 1924-25 and 100 individual high yielding plants separately harvested and analyzed. These plants were not therefore selected in 1923-24 but were merely multiplied in 1924-25, *i.e.*, apart from environmental conditions these beans should have given identical values for mean per cent. HCN, standard deviation and coefficient of variability with those of the parent samples of 1923-24. Actual values are set out in Table VI.

TABLE VI.

Mean per cent. HCN showing temporary bad effect of bad season on HCN content.

Strain		1923-24	1924-25 (Bulk)
M	A270/37	0·0052	0·0035
		0·0052	0·0040
	A278/61	0·0051	0·0035
G. G49/2-A207		0·0071	0·0045
Monywa 7. A142/82		0·0062	0·0035
K	K102/7	0·0059	0·0036
	K109/50	0·0059	0·0042
	K113/28	0·0052	0·0039
	K159/84	0·0056	0·0039
	K239/84	0·0059	0·0042
	K354/54	0·0063	0·0039
	K392/84	0·0061	0·0041

Without exception, the bulk samples of 1924-25 without any selection whatever show a very marked diminution in HCN content compared with the parent sample of 1923-24. The average values are 0·0058 per cent. HCN in 1923-24 and 0·0039 per cent. HCN in 1924-25. These values are well out of the range of probable error, reduction in HCN content due to a good season in 1924-25 amounting to approximately fifty per cent. Hence seasonal influences profoundly affect the HCN content of *pèbyugale.*

The years 1922-23 and 1924-25 were both excellent for the growth of *pèbyugale.* A large number of single plant selections were available from the 1922-23 crop and although the best of these were sown in 1923-24, others nearly as good were stored over 1923-24 and grown in 1924-25. It is to be expected that even under such conditions the 1924-25 crop would show a diminution in mean HCN content compared with 1922-23. That such was not the case is shown in Table VII.

TABLE VII.

Mean per cent. HCN.

Strain		1922-23	1924-25	Increase or decrease per cent.
M	111/1	0·0023	0·0038	+0·0015
	115	0·0023	0·0036	+0·0013
	127	0·0023	0·0034	+0·0011
G		0·0029	0·0048	+0·0019
Monywa 7		0·0041	0·0043	+0·0002
K	K102	0·0023	0·0034	+0·0011
	K109	0·0021	0·0033	+0·0012
	K113	0·0032	0·0031	—·00001
	K159	0·0027	0·0030	+0·0003
	K239	0·0026	0·0034	+0·0008
	K354	0·0024	0·0032	+0·0008
	K393	0·0022	0·0031	+0·0009

The average increase in HCN content of these twelve substrains in 1924-25 as compared with 1922-23 is 0·0009 per cent., an amount well out of the range of

probable error. Hence it follows that since rigorous selection in 1924-25 has resulted not in a decrease but in an increase of HCN content as compared with 1922-23, the influence of environmental factors is more important than selection for low HCN content in determining the percentage of HCN which *pèbyugale* may contain. This may be ascribed to the fact that although both 1922-23 and 1924-25 were good seasons for *pèbyugale*, 1922-23 was much more favourable than 1924-25.

There remains the possibility that an insufficient number of plants for direct selection was available in 1923-24 and 1924-25. The numbers were as follows :—

Number of individual plants analyzed.

Strain	1923-24	1924-25
M 111/1	9	*a*-30 *b*-31 *c*-12
Monywa 7	23	18
K 113	6	26
K 159	15	7

The chances of obtaining a plant with less than mean amounts of HCN are one in two if the distribution curve is normal. Reference to Figure 1 shows that the distribution curve for a large number of plants is normal. Hence if only six or seven plants are available for individual analysis there is a fair probability that half this number will have less HCN than mean amounts and even in such cases selection for low HCN content should be progressive.

Conclusions.

1. Environmental factors profoundly influence the HCN content of Burma beans.
2. Under ordinary field conditions the influence of environmental factors is more powerful in influencing the HCN content of Burma beans than is rigorous single plant selection.
3. Rigorous single plant selection during four years has not reduced the HCN content of Burma beans. Since especially favourable conditions over four or five successive seasons cannot be expected, the removal of HCN from Burma beans by single plant selection is an impossibility.

IV. EFFECT OF STORAGE ON HCN CONTENT OF BURMA BEANS.

Part of the bulk sample K grown in 1921-22 was used for storage tests with a view to ascertaining the change in activity of hydrolytic enzymes of the beans under varying conditions with increasing age. At the commencement of the experiment, *i.e.*, early in April 1922, the maximum amount of HCN which could be liberated by brewers' malt was 0·0041 per cent. Part of the sample was stored in the laboratory at Mandalay in an air-tight bottle fitted with a rubber stopper. Another portion was stored in gunny bags in a godown at Tatkon, while on June 30th, 1922, a portion of the sample stored in the air-tight glass bottle at Mandalay was transferred to another glass bottle and left open to the atmosphere. In August 1923 the sample stored in gunny bags at Tatkon was transferred to Mandalay. No attempt was made to artificially dry the air in any case.

Thirty grams of crushed beans were used for analysis in each case. In the first place, glucoside HCN was extracted both by hot water and by ethyl alcohol. It was soon found, however, that the hot water extraction was more efficient and after four separate trials at monthly intervals, alcohol extraction was discontinued, the hot water extraction method having given consistently higher results. That the hot water extraction method previously described extracts the whole of the glucoside was verified on three separate occasions, a third extraction of the beans with 300 c.c. of boiling water failing to yield any HCN. To find the maximum amount of HCN yielded by malt *plus* beans, varying amounts of malt from five grams upwards were added to thirty grams of beans. The results are given in Table VIII.

TABLE

Effect of storage on Burma beans—

	—	1 month	2 months	3 months	4 months	5 months	6 months	8 months	10 months	1 year	1 year 2 months
Sample A stored in glass bottle at Mandalay. Air-tight.	Glucoside HCN (Alcoholic extraction).	0·0009	0·0019	0·0017	0·0023	..	..	..	..	..	..
	Glucoside HCN (Water extraction).	0·0020	0·0027	0·0029	0·0029	..	0·0029	0·0046	0·0035	0·0024	..
	3rd water extraction	..	*nil*	*nil*	*nil*	..	..	..	..	..	..
	Auto-enzyme HCN .	0·0015	0·0019	0·0017	0·0020	..	0·0023	0·0023	0·0012	0·0021	..
	TOTAL HCN .	0·0041	0·0039	0·0041	0·0046	..	0·0052	0·0052	0·0029	0·0031	..
Sample B transferred from A on 30th June 1922 and left open to atmosphere.	Glucoside HCN (Water extraction).	..	..	..	..	0·0035	..	0·0046	0·0029	0·0027	0·0017
	Auto-enzyme HCN .	..	..	..	..	0·0023	..	0·0041	0·0017	0·0019	0·0033
	TOTAL HCN .	..	..	..	..	0·0059	..	0·0058	0·0023	0·0034	0·0038
Sample C stored in gunny bags at Tatkon. Transferred to Mandalay after 1 year 5 months.	Glucoside HCN (Water extraction).	..	..	..	..	..	0·0035	0·0064	0·0017	0·0019	0·0017
	Auto-enzyme HCN .	..	..	..	..	..	0·0029	0·0041	0·0017	0·0029	0·0045
	TOTAL HCN .	..	..	..	..	..	0·0058	0·0064	0·0023	0·0043	0·0045

VIII.

HCN content per cent.

1 year 3 months	1 year 6 months	1 year 8 months	1 year 10 months	2 years	2 years 2 months	2 years 4 months	2 years 5 months	2 years 6 months	2 years 7 months	2 years 8 months	2 years 9 months	2 years 10 months	2 years 11 months	3 years
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Traces	..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
0·0034	..	..	..	..	..	..	..	..	..	..	..	..	..	.
0·0007	0·0018	0·0010	0·0010	0·0017	0·0017	0·0010	0·0012	0·0017	0·0010	0·0013	0·0013	Trace	Trace	..
0·0024	0·0057	0·0043	0·0027	0·0030	0·0040	0·0030	0·0023	0·0037	0·0047	0·0030	0·0040	0·0030	0·0027	0·0040
0·0084	0·0060	0·0047	0·0025	0·0037	0·0082	0·0080	0·0057	0·0037	0·0080	0·0053	0·0060	0·0050	0·0043	0·0050

Results of storage tests.

Tests were carried out on individual samples as long as such samples lasted.

(1) *Storage in Air-tight bottle.*

(*a*) The total, glucosidal and auto-enzyme HCN rise gradually from the amount present at harvest to a maximum in September to November after which a very sharp fall occurs about January. The total and auto-enzyme HCN subsequently rise in amount.

(*b*) In general over the period of one year the relative amounts of HCN are as follows :—total HCN> glucosidal HCN> auto-enzyme HCN.

(2) *Storage in open bottle.*

(*a*) More rapid synthesis of total, glucosidal and auto-enzyme HCN than in the case of beans stored in a closed bottle occurs. The maxima and minima occur at the same times as for the sample stored in the closed bottle. Whereas in the case of total and auto-enzyme HCN synthesis of HCN occurs in the second year of storage, the glucosidal HCN shows a tendency to disappear altogether.

(*b*) During the first year of storage the relative amounts of HCN in various forms are as follows :—total HCN> glucosidal HCN> auto-enzyme HCN. Temporarily in the month of January this relationship does not hold because destruction of total HCN is more rapid than destruction of glucosidal HCN.

(*c*) Synthesis of total and auto-enzyme HCN is definitely indicated after storage for a year.

(3) *Storage in gunny bags.*

(*a*) The curves for total, glucosidal and auto-enzyme HCN closely follow those obtained for storage in the air-tight and closed bottles but the maxima are generally greater and the destruction of synthesised HCN more rapid. As in the cases of samples stored in bottles, HCN in all forms during the first year is at a maximum in November and at a minimum in January.

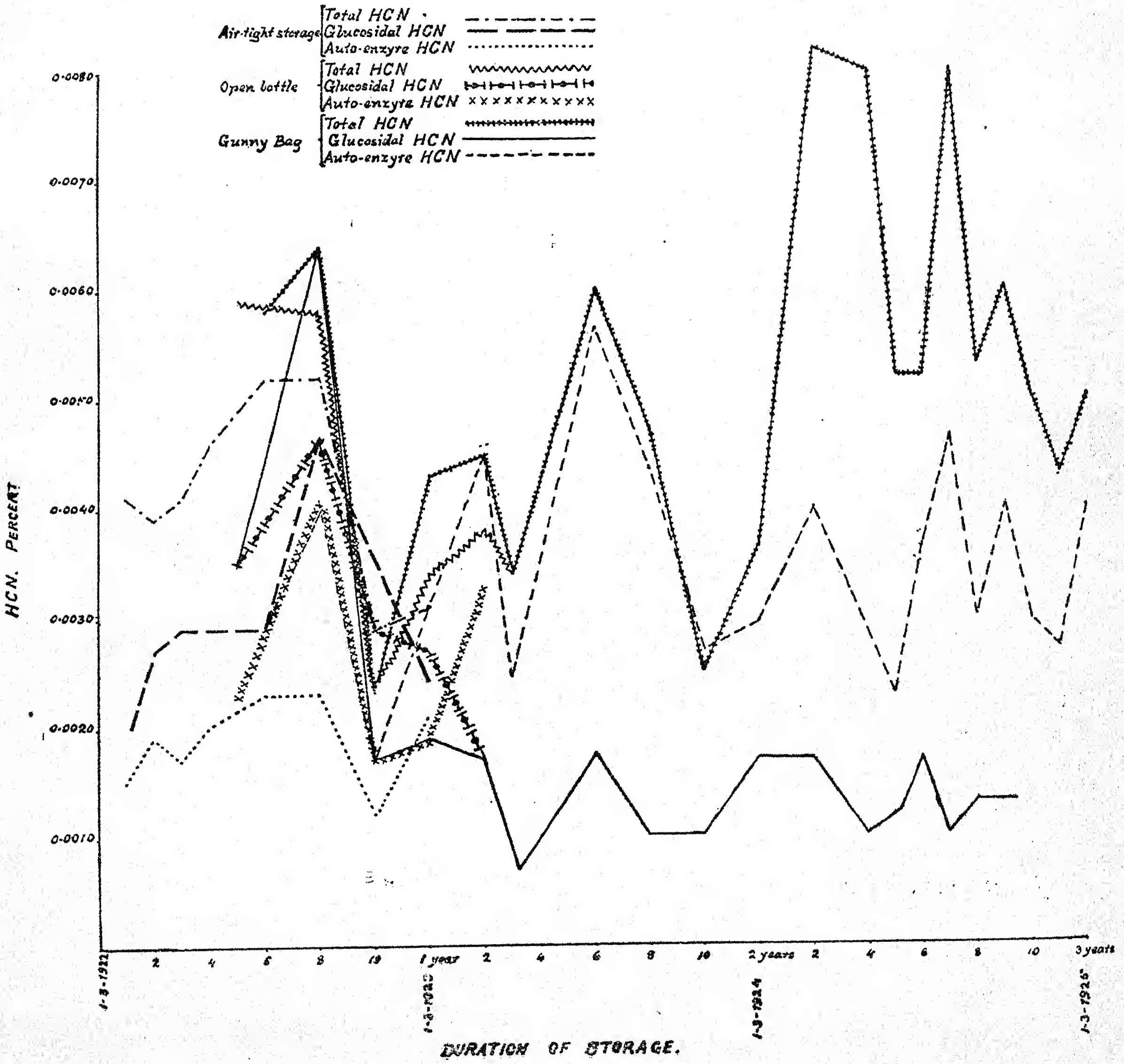
(*b*) In general during the first year of storage the following relationship holds good :—total HCN> glucosidal HCN> auto-enzyme HCN except for the fact that after January 1923 the auto-enzyme HCN becomes definitely greater in amount than the glucosidal HCN.

(*c*) For the further period of storage for two years the following relationship holds :—Total HCN> auto-enzyme HCN> glucosidal HCN with the exception that in January 1924 the auto-enzyme becomes temporarily very slightly greater than total HCN.

(*d*) During the second and third year of storage, synthesis of HCN occurs between the months of September and November followed by destruction of the HCN so formed in the month of January.

The results of storage tests are shown graphically in Figure II.

FIG. 2. *Results of storage tests of Burma beans.*



General conclusions concerning storage.

1. The amount of HCN in Burma beans depends upon the age of the sample and on the method of storage.

2. The activity of the hydrolytic enzymes in Burma beans likewise depends on the age of the beans and on the method of storage.

3. Synthesis of total, glucosidal and auto-enzyme HCN occurs during the hot, wet season. The HCN so synthesised is partially or completely destroyed during the subsequent cold weather.

4. The glucosidal HCN reaches its maximum during the first year of storage after which it is very small in amount in good samples of beans such as the one used for storage tests.

5. After storage for one year the total and auto-enzyme HCN become greater in amount than the glucosidal HCN and remain permanently so.

6. In the sample of beans used for the storage experiments, the total HCN remains consistently greater in amount than the auto-enzyme HCN except for a very brief period after storage for one year and ten months. This result is contrary to those usually obtained and may be due to the fact that the sample was a specially selected one. In the majority of old samples of beans examined, the auto-enzyme HCN has been definitely greater in amount than the total HCN.

7. The amount of HCN in Burma beans may vary during storage within extremely wide limits. It is therefore desirable that the age of the beans, method of storage and method by which HCN is liberated should be given when stating the percentage of HCN contained in any special sample.

8. A sample which contains not more than 0·0040 per cent. total HCN at harvest is unlikely to contain more than about 0·0080 per cent. HCN in any form, no matter how stored for a period of three years, provided that ordinary care is taken.

V. PRUSSIC ACID IN OTHER VARIETIES OF PHASEOLUS LUNATUS.

Three recently harvested samples of *Phaseolus lunatus*, Linn., *viz.*, *Lima* (Tiffin Bean), *Pèni* and *Pènet*, were examined by the usual methods to see whether the hydrolytic enzymes behaved similarly to those of *γèbyugale.* The *Lima* beans had been grown in Egypt but the *pèni* and *pènet* varieties had been grown at Mahlaing. The results of analysis are given in Table IX.

TABLE IX.

Per cent. HCN in Phaseolus lunatus varieties at harvest.

—	Lima	Pèni	Pènet
Glucosidal HCN	0·0027	0·0048	0·0340
Auto-enzyme HCN	0·0050	0·0034	0·0107
Total HCN using 5 grm. malt/30 beans	0·0057	0·0039	0·0160
,, ,, 10 ,, ,,	0·0045	0·0041	0·0160
,, ,, 20 ,, ,,	0·0053	0·0045	0·0160
,, ,, 30 ,, ,,	0·0060	0·0053	0·0207
,, ,, 40 ,, ,,	0·0055	0·0063	0·0274
,, ,, 50 ,, ,,	0·0064	0·0063	0·0213
,, ,, 60 ,, ,,	0·0064	0·0063	0·0331
,, ,, 70 ,, ,,	..	..	0·0360
,, ,, 80 ,, ,,	..	..	0·0384
,, ,, 90 ,, ,,	..	..	0·0397
,, ,, 100 ,, ,,	..	..	0·0413
,, ,, 110 ,, ,,	..	..	0·0413
,, ,, 120 ,, ,,	..	..	0·0413

The Lima and *pèni* samples are therefore quite good beans since the HCN content is low. On the other hand, the sample of *pènet* is one of the worst samples of *Phaseolus lunatus* hitherto encountered and may be described as containing dangerous amounts of HCN. All samples are lacking in hydrolytic enzymes, addition of brewers' malt giving increased yields of HCN compared with yields obtained by other methods, although extremely large amounts of glucosidal HCN are present in the sample of *pènet*.

It may therefore be concluded that lack of hydrolytic enzymes in *Phaseolus lunatus* is a general phenomenon in the newly-harvested crop. Further, if it be admitted that Burma beans are dangerous for human consumption, it is more than likely that every variety of *Phaseolus lunatus* is equally dangerous.

VI. INFLUENCE OF SOIL ON THE HCN CONTENT OF PHASEOLUS LUNATUS.

(*a*) LIMING EXPERIMENT AT PADU.

It has been suggested that the presence of large amounts of HCN in *Phaseolus lunatus* is due to richness of the soil in available nitrogen and that if the soil is poor in nitrogen the content of HCN in the beans will be low. Accordingly a poor red sandy soil at Padu was chosen, this soil being so sour that azotobacter do not thrive. It was thought that such a soil might yield beans containing small amounts of HCN, while in the limed plots, where nitrification would be more active, greater contents of HCN in the beans might result. Very little of the soil was available for the

experiment with the result that only six one-twentieth acre plots could be laid down. Numbers one and six were left untreated and numbers two, three, four and five dressed with lime in various amounts. The hydrogenion concentrations of the 1-5 water extracts were done at planting and harvest, the results being set out in Table X.

TABLE X.

Effect of liming on Padu Red soil (0″—7″).

Plot No.	Lime applied at the rate of lb. per acre	P_H at planting	P_H at harvest
1	*nil*	6·15	7·05
2	10,000	7·6	7·55
3	5,000	7·2	7·55
4	1,250	6·5	7·3
5	625	6·25	7·15
6	*nil*	6·15	6·9

The results were obscured owing to the fact that nodules of calcium carbonate are present in the subsoil of Padu Red and some of these are brought to the surface when ploughing. Hence the differences in P_H of the various plots were extremely small at harvest. Further, it was desired to have blank plots between each limed plot, but this was not possible because of the small amount of red soil available at this farm.

A sample of unselected bad bazaar beans was grown in all plots and bulk samples collected at harvest. Results are given in Table XI.

TABLE XI.

Effect of Liming on HCN content of pèbyugale grown on Padu Red soil.

—	Plot No.					
	1	2	3	4	5	6
Glucosidal HCN . .	0·0325	0·0354	0·0336	0·0418	0·0447	0·0418
Auto-enzyme HCN . .	0·0176	0·0174	0·0174	0·0174	0·0174	0·0261
TOTAL HCN . . .	0·0273	0·0261	0·0232	0·0232	0·0261	0·0261

The fact that glucosidal HCN was greater than the total HCN in the above sample is a phenomenon of common occurrence with bad unselected varieties at harvest.

No definite conclusion can be drawn from the above figures. Application of such heavy dressings of lime as 10,000 lb. per acre has not affected the HCN content of the beans significantly. The change of P_H resulting from liming this soil is not sufficiently great for definite results to be obtained even if alteration of P_H affects the HCN content of the beans. The rate of nitrification of the different plots would probably be substantially the same. Unfortunately, no other sour soil suitable for the growth of Burma beans is conveniently situated near Mandalay and hence the work could not be repeated. The results are quoted not to show the effect of different rates of nitrification but to show that fairly heavy liming is without effect on the HCN content of Burma beans.

(*b*) Comparison of soils at Mahlaing.

The samples of *pèni* and *pènet* already quoted were unselected varieties submitted by the Deputy Director of Agriculture, Myingyan Circle, in 1922-23. Whereas the *pèni* was a very good specimen, the *pènet* was one of the worst samples of *Phaseolus lunatus* ever examined. To discover if the respective soils on which the two samples had been grown in 1922-23 were in any way responsible for the low content of HCN in the case of *pèni* and for the high content of HCN in the case of *pènet*, these plots were halved and the *pèni* and *pènet* in 1923-24 were grown on both soils. Results are given in Table XII.

Table XII.

Effect of soils on HCN content per cent. of pèni and. pènet.

Season	Pèni plot		Pènet plot	
1922-23—				
Glucosidal HCN	0·0048		0·0340	
Auto-enzyme HCN	0·0034		0·0107	
Total HCN	0·0063		0·0413	
	Pèni	Pènet	Péni	Pènet
1923-24—				
Glucosidal HCN	0·0043	0·0464	0·0043	0·0470
Auto-enzyme HCN	0·0010	0·0145	0·0007	0·0261
Total HCN	0·0113	0·0261	0·0083	0·0261

Considering, in the first case, the effect of growing in different soils in the season 1923-24, it is seen that by growing *pèni* in the *pènet* soil, the auto-enzyme and total HCN are both slightly reduced, while the glucosidal HCN remains unaffected. On the whole, therefore, growing *pèni* in the *pènet* soil has tended to reduce the HCN content of *pèni*. On the other hand, in the case of *pènet*, growing in the *pèni* plot was without effect except that the auto-enzyme HCN was considerably reduced. It would appear, therefore, that the *pènet* soil tends to reduce the HCN content of *pèni* and that the *pèni* soil tends to reduce the HCN content of *pènet*.

Compared with the results for 1922-23, whether the *pèni* or *pènet* was grown in either of the two soils is of little importance, the HCN in certain forms being very considerably increased in 1923-24. The variation according to season therefore outweighs slight differences produced by soils. It is likely that the HCN content of the beans depends in some manner upon the growth period and this varies considerably from season to season, differences in prevailing temperature, rainfall, etc., being probably responsible. Further, in comparing differences produced by soils upon HCN content, it must be remembered that soils greatly different in physical texture cannot be compared as it is impossible to prepare greatly different soils so as to be ready for sowing and harvest at the same time. The life period of the crop is not the same in soils fundamentally different physically. The two soils compared above were not greatly different with the result that agricultural operations could be carried out simultaneously. It is concluded that the influence of such soils on the HCN content is negligibl ecompared with variations due to seasonal conditions.

VII. STATE OF COMBINATION OF HCN IN BURMA BEANS.

Dunstan and Henry[1] showed that the seeds of wild *Phaseolus lunatus* contain the glucoside phaseolunatin $C_{10}H_{17}O_6N$ which on hydrolysis with acids gave dextrose, acetone and HCN. They stated that the seeds of the cultivated plants do not contain the glucoside. L. Guignard[2] later showed that the seeds of cultivated *Phaseolus lunatus* also contain HCN in minute amounts. Kohn-Abrest[3] stated that more than one cyanogenetic glucoside was present. L. Rosenthaler[4] stated that HCN occurs only in glucosidal combination in the seeds of *Phaseolus lunatus*.

On many occasions the author had noticed that whereas large quantities of HCN could be driven off from crushed Burma beans by simply steaming, none could be driven off unless the beans were first crushed. Only bad bazaar samples yielded measurable quantities of HCN by the process of steaming and with such samples

[1] Dunstan and Henry, *Proc. Roy. Soc.*, 1903, 72, 285-294.
[2] L. Guignard, *Compt. Rend.*, 1906, 142, 545-553.
[3] Kohn-Abrest, *Compt. Rend.*, 1906, 143, 182-184.
[4] L. Rosenthaler, *Schweiz. Apoth. Zeit.*, 1919, 57. 571-576.

in certain cases a very large proportion of the total HCN present could be driven off. For the sake of brevity this HCN will be referred to as *free* HCN. Whether this HCN was in a different state of combination from the HCN not so evolved required investigation.

The determination of such free HCN in one sample gave the results set out in Table XIII.

TABLE XIII.

Free HCN per cent. in Burma beans.

—	Crushed beans		Uncrushed beans
	No. 1	No. 2	
First 100 c.c. distillate	0·0050	0·0079	*nil*
Second 100 c.c. distillate	0·0023	*nil*	*nil*
Third 100 c.c. distillate	0·0010	*nil*	*nil*
Fourth 100 c.c. distillate	*nil*	*nil*	*nil*
Fifth 100 c.c. distillate	*nil*	*nil*	*nil*
Sixth 100 c.c. distillate	*nil*	*nil*	*nil*
Seventh 100 c.c. distillate	*nil*	*nil*	*nil*
TOTAL .	0·0083	0·0079	*nil.*

Two lots of crushed beans were distilled with steam, the first one slowly and the second one rapidly. A third lot of uncrushed beans was distilled as a check. The rapid and slow distillations gave approximately the same yield of free HCN.

It was considered possible that the fineness of grinding might influence the yield of free HCN. To test this possibility a sample of crushed beans was separated into two fractions by sieves using the one millimeter sieve to effect a separation. Duplicate lots of each fraction were steam distilled with the result given in Table XIV.

TABLE XIV.

Free HCN per cent. in Burma beans.

Experiment No.	Fraction	
	>1 mm.	<1 mm.
1	0·0033	0·0050
2	0·0033	0·0050

To check these results another large sample of bad bazaar beans was separated into three fractions, each of which was steam distilled and the free HCN estimated. The results are given in Table XV.

TABLE XV.

Free HCN per cent. in Burma beans.

Fraction		Per cent. HCN	
3 mm.—1 mm. . .	(*a*) First 300 c.c. distillate . . .	0·0267	0·0267
	(*b*) Second 300 c.c. distillate . .	*nil*	
	(*c*) Third 300 c.c. distillate . .	*nil*	
1 mm.—No. 60 sieve .	(*a*) First 300 c.c. distillate . .	0·0233	0·0233
	(*b*) Second 300 c.c. distillate . .	*nil*	
	(*c*) Third 300 c.c. distillate . .	*nil*	
<No. 60 sieve . .	(*a*) First 300 c.c. distillate . .	0·0060	0·0060
	(*b*) Second 300 c.c. distillate . .	*nil*	
	(*c*) Third 300 c.c. distillate . .	*nil*	

Whereas in the experiment recorded in Table XIV the smallest fraction gave the higher yield of free HCN, in that recorded in Table XV the smallest fraction gave the lowest yield of free HCN. The possibility that the interval between crushing and distilling influenced the yield of free HCN was next examined. For this purpose a large sample of beans was crushed and portions distilled at intervals, the free HCN evolved being recorded in Table XVI.

TABLE XVI.

Free HCN per cent. in Burma beans. Influence of delay in distillation.

Interval before distillation		Free HCN per cent.	
Immediate distillation	(*a*) First 300 c.c. distillate	0·0018	0·0022
	(*b*) Second 300 c.c. distillate	0·0004	
15 minutes	(*a*) First 300 c.c. distillate	0·0018	0·0026
	(*b*) Second 300 c.c. distillate	0·0008	
30 minutes	(*a*) First 300 c.c. distillate	0·0056	0·0064
	(*b*) Second 300 c.c. distillate	0·0008	
One hour	(*a*) First 300 c.c. distillate	0·0052	0·0058
	(*b*) Second 300 c.c. distillate	0·0006	
Two hours	(*a*) First 300 c.c. distillate	0·0070	0·0084
	(*b*) Second 300 c.c. distillate	0·0014	

It therefore appeared likely that the liberation of free HCN was due to the action of crushing, the enzymes then being able to attack the glucoside although the beans were comparatively dry. The possibility that the enzymes were able to attack the glucoside during the very brief period in which the steam was moistening and heating the flasks of beans was regarded as unlikely. Further, the interval was approximately the same in the experiments recorded in Tables XV and XVI and in addition, a slow and rapid stream of steam gave approximately equal amounts of free HCN in the experiments recorded in Table XIII. Unless a portion of the glucosidal HCN is changed into a form not recoverable by the ordinary hot water extraction method, the amount of free HCN evolved on steaming *plus* the residual amount left in the steamed beans should be the same as that obtained directly by the ordinary hot water extraction method. Two separate samples of bad bazaar beans were therefore examined to test this possibility with results given in Table XVII.

TABLE XVII.

Per cent. HCN in Burma beans.

	Sample A		Sample B	
	Crushed beans	Uncrushed beans	Crushed beans	Uncrushed beans
Free HCN—				
(a) First 300 c.c. distillate	0·0158	*nil*	0·0060	*nil*
(b) Second 300 c.c. distillate	*nil*	*nil*	*nil*	*nil*
(c) Third 300 c.c. distillate	*nil*	*nil*	*nil*	*nil*
Residual glucosidal HCN after removal of free HCN.	0·0251	..	0·0340	..
Glucosidal HCN	..	0·0413	..	0·0400
Total HCN (Glucosidal)	0·0409	0·0413	0·0400	0·0400

In both samples A and B, the free HCN was therefore obtained from the glucosidal HCN and is normally recovered as glucosidal HCN in the usual hot water extraction method when the beans are not crushed.

If only the glucoside phaseolunatin is present in Burma beans, decomposition of this glucoside should yield equimolecular amounts of acetone and HCN, and relative weights of $\frac{CH_3CO.CH_3}{HCN}=2{\cdot}15$ should be obtained. Experiments in which both $CH_3CO.CH_3$ and HCN were estimated as evolved in the free, glucosidal, auto-enzyme and total HCN estimations were carried out. The distillate from each of these estimations was halved, the HCN being estimated as prussian blue in one half and the remaining half made alkaline with NaOH and redistilled. In the latter half the $CH_3CO.CH_3$ was estimated as iodoform. Tests using HCN and $CH_3CO.CH_3$ in equimolecular proportions gave excellent results so long as not less than 0·0030 per cent. HCN and corresponding amounts of acetone were obtained. If smaller amounts were obtained, the method could not be relied upon to give accurate results. The presence of ethyl alcohol in the estimation of auto-enzyme and total HCN was possible or even likely but in the method of estimation of acetone using ten cubic centimetres of fifteen per cent. KI solution and ten cubic centimetres of ten per cent. KOH solution in a bulk of 400 c.c., together with twenty-five cubic centimetres of N/10 Iodine, the time of reaction being fifteen minutes. it was found that the presence of ethyl alcohol in comparatively large amounts did not interfere with the estimation of acetone.

The results of analysis are given in Table XVIII.

TABLE XVIII.

HCN and $CH_3CO.CH_3$ evolved from Burma beans.

—	Per cent. HCN	Per cent. $CH_3CO.CH_3$	Ratio $\frac{CH_3CO.CH_3}{HCN}$
1. Free HCN	0·0153	0·0365	2·39
2. Residual Glucoside from 1	0·0128	0·0212	1·66
3. Glucosidal HCN	0·0287	0·0625	2·22
4. Auto-enzyme HCN	0·0284	0·0749	2·64
Residual glucosidal HCN	0·0013	..	..
5. Total HCN using 30 grm. beans *plus* 10 grm. malt	0·0313	0·0690	2·20
Residual glucosidal HCN	0·0027	..	..
6. Total HCN using 30 grm. beans *plus* 20 grm. malt	0·0313	0·0787	2·51
Residual glucosidal HCN	0·0030	..	..
7. Total HCN using 30 grm. beans *plus* 30 grm. malt	0·0273	0·0590	2·16
Residual glucosidal HCN	0·0023	..	..
8. Total HCN using 30 grm. beans *plus* 40 grm. malt	0·0244	0·0575	2·35
Residual glucosidal HCN	0·0025	..	..
9. Total HCN using 30 grm. beans *plus* 50 grm. malt	0·0244	0·0633	2·59
Residual glucosidal HCN	0·0027	..	..

Except in the case of number 2 in which residual glucoside was estimated after removal of free HCN, the ratio $\frac{CH_3CO.CH_3}{HCN}$ varied between 2·16 and 2·64. Considering that such small amounts of $CH_3CO.CH_3$ and HCN are present, the agreement is reasonably good except in the case of number 2. Further, the weight of beans used for estimation in each case was sixty grams only so that the actual weights of $CH_3CO.CH_3$ and HCN obtained were only thirty per cent. of the figures recorded in Table XVIII. It will be noted that the free HCN *plus* residual glucosidal HCN again very closely checked the HCN obtained as glucosidal HCN by hot water extraction of uncrushed beans. In Table XVIII in experiments 4, 5, 6, 7, 8 and 9, the beans remaining after distillation of HCN were again extracted with hot water and the HCN in the extract determined by acid hydrolysis. Further definite amounts of HCN were obtained in all cases showing that even the method of liberation of HCN with malt (total HCN) does not set free all the HCN in Burma beans. In these cases the ratio $\frac{CH_3CO.CH_3}{HCN}$ was not determined as with such small amounts it was known that the determination was not trustworthy.

It was therefore decided to repeat the experiment using bad bazaar samples of new and old beans, doing the experiments for auto-enzyme, glucosidal and total HCN in quadruplicate. The free HCN was not determined. The results of this test are given in Tables XIX and XX, for new and old beans respectively.

TABLE XIX.

Relative amounts of HCN and $CH_3CO.CH_3$ in new bazaar sample of Burma beans.

Method of estimation	Per cent. HCN	Per cent. $CH_3CO.CH_3$	Ratio $\frac{CH_3CO.CH_3}{HCN}$	Mean Ratio $\frac{CH_3CO.CH_3}{HCN}$
1. Auto-enzyme HCN	0·0019 0·0019 0·0020 0·0019	0·0040 0·0041 0·0036 0·0036	2·09 2·14 1·78 1·84	1·97
2. Glucosidal HCN	0·0055 0·0035 0·0045 0·0043	0·0138 0·0080 0·0122 0·0125	2·50 2·28 2·70 2·90	2·59
3. Total HCN $\frac{40 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0016 0·0017 0·0017 0·0017	0·0050 0·0052 0·0051 0·0049	3·09 3·03 3·02 2·89	3·01
4. Total HCN $\frac{80 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0021 0·0021 0·0020 0·0019	0·0065 0·0059 0·0056 0·0053	3·08 2·82 2·82 2·78	2·87
5. Total HCN $\frac{120 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0028 0·0024 0·0033 0·0030	0·0068 0·0062 0·0063 0·0065	2·43 2·57 1·92 2·17	2·27
6. Total HCN $\frac{160 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0033 0·0030 0·0031 0·0032	0·0072 0·0077 0·0073 0·0072	2·18 2·58 2·28 2·25	2·34
7. Total HCN $\frac{200 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0031 0·0030 0·0032 0·0030	0·0081 0·0077 0·0075 0·0064	2·62 2·58 2·36 2·14	2·42

Relative amounts of HCN and $CH_3CO.CH_3$ in new bazaar sample of Burma beans—contd.

Method of estimation	Per cent. HCN	Per cent. $CH_3CO.CH_3$	Ratio $\frac{CH_3CO.CH_3}{HCN}$	Mean Ratio $\frac{CH_3CO.CH_3}{HCN}$
8. Total HCN $\frac{240 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0033 0·0031 0·0036 0·0035	0·0074 0·0078 0·0074 0·0075	2·24 2·51 2·07 2·15	2·24
9. Total HCN $\frac{320 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0035 0·0036 0·0036 0·0036	0·0081 0·0088 0·0085 0·0072	2·30 2·44 2·37 2·00	2·28
10. Total HCN $\frac{400 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0038 0·0026 0·0033 0·0038	0·0099 0·0065 0·0077 0·0087	2·60 2·49 2·33 2·29	2·45
11. Total HCN $\frac{480 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0042 0·0036 0·0034 0·0036	0·0102 0·0092 0·0068 0·0087	2·42 2·55 1·96 2·41	2·35
12. Total HCN $\frac{560 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0036 0·0036 0·0036 0·0036	0·0082 0·0081 0·0085 0·0082	2·27 2·25 2·36 2·28	2·29
13. Total HCN $\frac{640 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0036 0·0036 0·0040 0·0040	0·0087 0·0083 0·0088 0·0093	2·42 2·31 2·20 2·32	2·31
14. Total HCN $\frac{720 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0042 0·0040 0·0040 0·0040	0·0089 0·0085 0·0088 0·0093	2·13 2·11 2·20 2·33	2·19
15. Total HCN $\frac{800 \text{ grm. malt}}{100 \text{ grm. beans}}$	0·0033 0·0059 0·0040 0·0043	0·0090 0·0097 0·0099 0·0099	2·73 1·66 2·46 2·29	2·28

TABLE XX.

Relative amounts of HCN and $CH_3CO.CH_3$ in old bazaar sample of Burma beans.

Method of estimation	Per cent. HCN	Per cent. $CH_3CO.CH_3$	Ratio $\frac{CH_3CO.CH_3}{HCN}$	Mean Ratio $\frac{CH_3CO.CH_3}{HCN}$
1. Auto-enzyme HCN	0·0047 0·0045 0·0049 0·0049	0·0111 0·0108 0·0109 0·0103	2·36 2·41 2·22 2·10	2·27
2. Glucosidal HCN	0·0031 0·0031 0·0033 ..	0·0077 0·0085 0·0077 ..	2·48 2·74 2·33 ..	2·52
3. Total HCN $\frac{\text{40 grm. malt}}{\text{100 grm. beans}}$	0·0030 0·0035 0·0038 0·0031	0·0067 0·0081 0·0071 0·0074	2·22 2·31 2·02 2·38	2·23
4. Total HCN $\frac{\text{80 grm. malt}}{\text{100 grm. beans}}$	0·0038 0·0040 0·0042 0·0038	0·0073 0·0086 0·0093 0·0077	1·92 2·15 2·22 2·02	2·08
5. Total HCN $\frac{\text{120 grm. malt}}{\text{100 grm. beans}}$	0·0035 0·0033 0·0031 0·0033	0·0080 0·0089 0·0093 0·0091	2·29 2·71 3·00 2·76	2·69
6. Total HCN $\frac{\text{160 grm. malt}}{\text{100 grm. beans}}$	0·0038 0·0035 0·0035 0·0036	0·0096 0·0088 0·0090 0·0095	2·52 2·52 2·57 2·76	2·59
7. Total HCN $\frac{\text{200 grm. malt}}{\text{100 grm. beans}}$	0·0036 0·0040 0·0036 0·0038	0·0089 0·0100 0·0089 0·0109	2·48 2·50 2·42 2·85	2·56
8. Total HCN $\frac{\text{240 grm. malt}}{\text{100 grm. beans}}$	0·0031 0·0033 0·0035 0·0033	0·0065 0·0093 0·0084 0·0087	2·08 2·82 2·41 2·63	2·47
9. Total HCN $\frac{\text{280 grm. malt}}{\text{100 grm. beans}}$	0·0033 0·0033 0·0036 0·0033	0·0088 0·0090 00092 0·0088	2·66 2·73 2·56 2·67	2·65
10. Total HCN $\frac{\text{320 grm. malt}}{\text{100 grm. beans}}$	0·0036 0·0035 0·0036 0·0037	0·0090 0·0088 0·0098 0·0087	2·49 2·51 2·71 2·36	2·52

It will be noted that in the case of new beans the ratio $\frac{CH_3CO.CH_3}{HCN}$ varies from 1·97 to 3·01. If the results in which the per cent. HCN is 0·0030 or greater are considered, the ratio is very much more constant, varying only from 2·19 to 2·59. It is believed that the extreme values of 1·97 and 3·01 are due to the very small amounts of HCN and $CH_3CO.CH_3$ present in these particular cases.

In the analysis of old bazaar beans quoted in Table XX the amounts of HCN were constantly greater than 0·0030 per cent. and in this series the ratio $\frac{CH_3CO.CH_3}{HCN}$ varies only between 2·08 and 2·69.

In consideration of the fact that only small amounts of HCN and $CH_3CO.CH_3$ are present, the agreement of the figures may be considered to be fair and as a result it is unlikely that any other glucoside besides phaseolunatin is present in Burma beans. If another glucoside is present, it probably contains equimolecular proportions of HCN and $CH_3CO.CH_3$ or exists in very small amounts.

VIII. SUMMARY.

1. It is not possible to continuously reduce the HCN content of Burma beans by single plant selection because of interference of environmental factors.

2. The amount of HCN in Burma beans at any given time depends upon the age of the sample and upon the method of storage.

3. The activity of the hydrolytic enzyme or enzymes of Burma beans likewise depends upon the age of the sample and upon the method of storage.

4. Synthesis of HCN occurs in stored beans in the hot, humid season in Burma. The HCN so synthesised is destroyed either completely or partially during the subsequent cold season.

5. The portion of the HCN which can be extracted by hot water (glucosidal HCN) reaches a maximum in the first year of storage and afterwards becomes very small in amount in good samples of beans.

6. After storage for one year the total and auto-enzyme HCN become greater in amount than the glucosidal HCN and remain so during the second and third year of storage, *i.e.*, the total duration of the storage tests.

7. The actual variation in amount of HCN contained in Burma beans is considerable. The relative amounts obtained likewise vary considerably according to whether the methods described for estimation of glucosidal, auto-enzyme or total HCN are used for estimation. It is therefore advisable to state the age of the beans, method of storage and method by which HCN is liberated when stating what percentage of HCN is contained in any sample.

8. No single method of estimation gives the actual total content of HCN. After the action of malt upon beans a further amount of HCN can be obtained by hot water extraction followed by acid hydrolysis.

9. A newly harvested sample of beans which contains not more than 0·0040 per cent. HCN as liberated by malt is unlikely to contain more than double this amount of HCN at any time within three years if reasonably carefully stored.

10. Comparative inactivity of the hydrolytic enzymes or enzyme in *Phaseolus lunatus* at harvest is common to other varieties besides Burma beans.

11. Other varieties of *Phaseolus lunatus* are liable to contain as much HCN as Burma beans.

12. Fairly heavy liming of the soil on which Burma beans are grown does not sensibly affect the HCN content of the beans.

13. Small variations in soil do not significantly affect the HCN content of Burma beans. Seasonal variations considerably outweigh other causes of variation.

14. The HCN which can be removed from freshly crushed Burma beans by steaming is in glucosidal combination.

15. It is probable that all the HCN in Burma beans is present as one glucoside, phaseolunatin.

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CONTENTS.

BANGALORE MAINTENANCE EXPERIMENTS.

(FIRST SERIES)

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Object of the Experiment.

These experiments have been undertaken with the object of carrying out a systematic study of the chief Indian roughages. We possess a certain amount of information concerning our concentrates. We can assign fairly definite food values to very many of them. With the Indian roughages the situation is altogether different. We do not know the elementary facts regarding their digestibility, energy value or other characteristics. Further, as the roughage forms the bulk of the ration, malnutrition and nutritional diseases almost invariably arise from deficiencies in the roughage. Work on the roughages is therefore urgently needed. It is not likely that the information required can be procured from a rapid sequence of digestion trials. Such experiments give very little extra information and that is liable to be misleading because the animals are not given time to settle down to the ration. To obtain reliable data time must be devoted to the test. A course of feeding has to be persisted in.

Procedure.

Three well matched pairs of mature bullocks were selected for the experiment. One animal of each pair was fed on rice straw, the other on baled hay. The concentrate ration was identical for each pair of animals. The live weights of the three pairs were approximately 1,000 lb., 750 lb. and 500 lb., respectively. That is to say, the experiment was so designed that some observations regarding the

requirements in relation to body weight could also be made. The following statement shows the distribution of the animals for the experiment :—

—	Approximate live weight in lb.	Roughage fed
Bullock No.		
1	1,000	Rice straw.
2	1,000	Hay.
3	750	Rice straw.
4	750	Hay.
5	500	Rice straw.
6	500	Hay.

The intention was to feed a maintenance ration for a long period and to study the effect of the food. The experiment did not run very smoothly. The ration fixed after preliminary trials was found to produce a live weight increase which was too rapid to be suitable. The trial had to be stopped therefore. One animal, No. 6, developed nasal granuloma during this period. At the conclusion of the trial it was treated with tartar emetic injections and made fair recovery. The second test was carried out then with a smaller allowance of concentrate, the food was much better adjusted and the live weight increases were less rapid. Owing to the illness of the animal referred to above, however, this second test was considerably delayed and therefore also could not be continued as long as it was wished. During the feeding tests the live weights were determined every day and the food consumption was controlled and accurately determined. Digestion experiments were carried out at three stages of the feeding. The results obtained will be considered under the following heads :—

1. Digestion experiments with rice straw.
2. Digestion experiments with hay.
3. Estimation of the net energy values of the roughages.
4. Physiological effects of the roughages.

A note on the method employed in collecting the urine may be added here. The elaborate method devised by the writer at Pusa has apparently been adapted with modifications elsewhere. It may help other workers to know that we have abandoned the Pusa procedure at Bangalore and have adopted a very simple expedient which is effective and extremely easy to carry out. The bag and harness remain exactly as in the old method, but instead of a long rubber tube we now use a tube one inch long. This is closed with a press clip. The attendant has merely to draw off the

urine from the bag at frequent intervals and the animal must not be allowed to sit down when there is urine in the bag. The work is done on an ordinary stall floor, the animal is absolutely free and we have not recorded more than one case in which urine was lost.

Experimental Results.

Digestibility of rice straw. The results of the three digestion experiments are given in Table I. The figures for digestion of organic matter and total carbohydrates are remarkably regular. There is very little difference between the individuals, and the averages for the three periods are practically identical. The regularity of the figures is undoubtedly due to the fact that the animals were thoroughly accustomed to the food and ate regularly. The variations in the digestion of protein

TABLE I.

Digestion coefficients of rice straw.

—	Bullock No.	Dry matter	Organic matter	Protein	Ether extract	Fibre	Nitrogen free extract	Carbo-hydrates
1st Test	1	55·47	62·30	7·36	43·27	69·37	60·73	64·57
	3	52·97	60·44	16·12	53·66	68·15	57·10	62·00
	5	52·22	59·88	7·22	35·40	67·48	57·28	61·81
AVERAGE	..	53·55	60·87	10·23	44·11	68·33	58·37	62·79
2nd Test	1	55·01	62·62	12·26	44·54	77·43	58·03	64·54
	3	50·00	57·23	5·56	34·71	73·24	52·15	59·22
	5	53·98	61·02	12·35	35·12	73·59	57·57	62·04
AVERAGE	..	52·99	60·29	10·06	38·12	74·75	55·92	62·23
3rd Test	1	54·73	61·25	7·97	40·55	69·25	59·62	63·44
	3	54·10	59·48	19·99	54·67	66·56	57·33	61·00
	5	55·37	61·27	11·72	48·81	68·81	59·58	63·24
AVERAGE	..	54·73	60·67	13·23	48·01	68·21	58·84	62·56

and ether extract are not significant. They refer to very small quantities as will be seen below. An important point in this table is that the first test in which the protein given was very high yielded digestion figures which cannot be distinguished from the figures of the two succeeding tests in which the protein was very much lower. Halving the protein in the ration therefore has had no effect upon the digestibility of the roughage. This result is somewhat unexpected.

Table II gives the average composition, average digestion coefficients, and the average amounts of nutrients digested from 100 lb. of dry substance. The last set

TABLE II.

Composition, average digestion coefficients, and amounts digested from 100 lb. dry substance for each experiment.

—	Dry matter	Organic matter	Protein	Ether extract	Fibre	Nitrogen free extract	Carbo-hydrates
Composition—							
1st Test	100·00	83·15	2·67	1·16	35·17	44·14	79·31
2nd „	100·00	81·26	2·75	·59	26·13	51·78	77·91
3rd „	100·00	82 91	2·93	·84	31·44	47·71	79·15
AVERAGE .	100·00	82·41	2·79	·86	30·91	47·88	78·79
Average digestion coefficients—							
1st Test	53·55	60·87	10·23	44·11	68·33	58·37	62·79
2nd „	52·99	60·29	10·06	38·12	74·75	55·92	62·23
3rd „	54·73	60·67	13·23	48·01	68·21	58·84	62·56
AVERAGE .	53·54	60·61	11·17	43·41	70·43	57·71	62·53
Amounts digested from 100 lb. dry substance—							
1st Test	53·55	50 61	·27	·51	24·03	25·77	49·80
2nd „	52·99	48·99	·28	·22	19·53	28·98	48·48
3rd „	54·47	50·31	·39	·40	21·44	28·07	49·52
AVERAGE .	53·54	49·97	·313	·380	21·67	27·60	49·27

of figures is derived from nine separate tests which all gave concordant results. These figures must therefore be accepted as an accurate measure of the digestibility of our rice straw.

Table III gives data from other sources for purposes of comparison. The Pusa figures shown here are published for the first time. They are the average of a number

TABLE III.

Comparison of Bangalore figures with other data.

—	Dry matter	Organic matter	Protein	Ether extract	Fibre	Nitrogen free extract	Carbo-hydrates
Composition—							
Pusa	100·00	82·97	2·43	1·25	35·74	43·57	79·29
Bangalore	100·00	82·41	2·79	·86	30·91	47·88	78·79
American	100·00	84·32	4·22	1·51	36·22	42·38	78·59
Average digestion coefficients—							
Pusa old	47·0	57·1	..	60·2	72·0	44·1	..
Pusa new	52·37	58·84	..	41·34	72·96	41·95	61 22
Bangalore	53·54	60·61	11·17	43·41	70·43	57·71	62·53
American	..	49 97	22·0	23·0	59·0	46·6	52·0
Amounts digested from 100 lb. dry substance—							
Pusa	52·37	48·82	..	·52	25·89	18·28	48·54
Bangalore	53·54	49·97	·31	·38	21·67	27·60	49·27
American	..	42·14	·93	·35	21·37	19·50	40·87

of tests carried out by this Section when the work on animal nutrition was initiated there by the writer. There is very little difference between the Pusa and Bangalore results. They confirm one another and prove that a real and very considerable difference exists between Indian and American digestion data for rice straw. In Pusa and Bangalore 100 lb. dry straw yielded 48·8 and 49·9 lb. of digestible organic matter respectively. In America only 42·1 lb. were obtained. Clearly our rice straw fed to Indian cattle must possess a higher net energy value than that allowed for rice straw in America. There are two possible reasons for the higher digestion found at Bangalore. Either our animals have a better digestive capacity for such roughage or the American straw is less digestible. Judging by chemical composition there is no reason why the American straw should be less digestible. Indeed, its higher protein content might lead one to believe that it would be more easily digested. On the whole, it appears likely that our animals have a better digestive capacity for roughage. The same conclusion was reached in experiments described in two previous papers.

2. *Digestibility of baled hay.* The digestion coefficients obtained with baled hay are shown in Table IV. Here again the digestion attained by the three animals

TABLE IV.

Digestion coefficients of hay.

—	Bullock No.	Dry matter	Organic matter	Protein	Ether extract	Fibre	Nitrogen free extract	Carbo-hydrates
1st Test	2	44·50	47·00	..	3·97	52·43	45·80	48·91
	4	45·27	47·77	..	25·74	54·22	45·03	49·30
	6	47·00	49·50	6·38	4·50	54·90	47·90	51·15
AVERAGE	..	45·59	48·09	2·13	11·37	53·85	46·24	49·79
2nd Test	2	52·94	58·83	..	62·33	74·29	50·35	59·12
	4	54·56	59·40	..	54·56	74·82	53·57	61·35
	6	50·74	54·62	..	56·73	74·10	46·43	56·57
AVERAGE	..	52·75	57·62	..	57·87	74·40	50·12	59·01
3rd Test	2	54·38	57·21	8·13	44·60	60·33	56·85	57·39
	4	52·32	56·58	2·42	47·72	61·65	54·27	57·18
	6	51·13	53·59	..	52·07	57·79	53·58	55·24
AVERAGE	..	52·61	55·46	3·52	48·13	59·92	54·90	56·60

in each test is fairly uniform. In the case of baled hay, however, the figures for the three periods do not agree at all closely. The material used during the first test was decidedly inferior in quality and it was less perfectly digested than the fodder used later. Table V gives the average composition and digestibility. The

TABLE V.

Average composition, average digestion coefficients, and amounts digested from 100 lb. dry substance.

—	Dry matter	Organic matter	Protein	Ether extract	Fibre	Nitrogen free extract	Carbo-hydrates
omposition—							
1st Test	100·00	91·78	2·51	1·25	40·82	47·20	88·02
2nd ,,	100·00	87·81	2·27	1·33	31·52	54·53	86·05
3rd ,,	100·00	90·13	2·47	1·03	34·19	52·50	86·69
AVERAGE	100·00	89·91	2·42	1·20	35·51	51·41	86·92
Average digestion coefficients—							
1st Test	45·59	48·09	2·13	11·37	53·85	46·24	49·79
2nd ,,	52·75	57·62	..	57·87	74·40	50·12	59·01
3rd ,,	52·61	55·46	3·52	48·13	59·92	54·90	56·60
AVERAGE	50·32	53·72	1·88	39·12	62·72	50·42	55·13
Amounts digested from 100 lb. dry substance—							
1st Test	·45·59	44·14	·053	·142	21·98	21·82	43·82
2nd ,,	52·75	50·60	..	·769	23·45	27·33	50·78
3rd ,,	52·61	49·99	·087	·494	20·48	28·82	49·06
AVERAGE	50·32	48·24	·047	·468	21·97	25·99	47·89

last set of figures is derived from nine tests and though the separate data are not concordant the final result is probably a fair estimate of the average quality of this class of roughage. The composition of the hay used during the three tests is worth examining. There is only one striking difference between the 3 samples and it lies in the percentage of fibre. The fibre content of the first sample, the one which gave low digestion results, is high. In this case, when comparing similar material, it appears that digestibility is largely dependent upon a low fibre content. It need scarcely be said that a rule of this kind can only be applied with the very greatest caution for, after all, in every one of these samples the most digestible constituent is the fibre itself. Table VI contains data for purposes of comparison. With regard

TABLE VI.

Comparison of Bangalore figures with other data.

—	Dry matter	Organic matter	Protein	Ether extract	Fibre	Nitrogen free extract	Carbo-hydrates
Composition—							
Indian—							
Meerut 52	100·00	84·07	1·79	1·41	29·79	51·07	80·86
Ambala 478	100·00	86·26	3·41	1·78	33·85	47·22	81·07
Bundelkhund 639	100·00	91·47	1·46	1·36	35·41	53·23	88·64
Bangalore (ex)	100·00	89·91	2·42	1·20	35·51	51·41	86·92
American—							
Meadow Fescue	100·00	92·07	7·70	2·26	34·43	47·68	82·11
Prairie Hay	100·00	91·77	8·56	2·78	32·62	47·81	80·43
Timothy early bloom	100·00	94·72	7·23	2·98	33·33	50·69	84·52
Timothy late bloom	100·00	94·71	6·46	3·29	33·25	51·70	84·96
Average	100·00	93·32	7·49	2·83	33·53	49·47	83·00
Average digestion coefficients—							
Bangalore	50·32	53·72	1·88	39·12	62·72	50·42	55·13
Meadow Fescue	..	61·26	52·00	54·00	67·00	59·00	62·36
Prairie Hay	..	49·51	..	42·00	58·00	53·00	55·03
Timothy early bloom	..	59·92	57·00	48·00	57·00	63·00	60·59
Timothy late bloom	..	53·07	43·00	51·00	46·00	59·00	53·91
Amounts digested from 100 lb. dry substance—							
Bangalore	52·32	48·24	·047	·468	21·97	25·99	47·89
Meadow Fescue	..	56·40	4·000	1·220	23·07	28·13	51·20
Prairie Hay	..	45·43	..	1·170	18·92	25·34	44·26
Timothy early bloom	..	56·76	4·12	1·43	19·28	31·93	51·21
Timothy late bloom	..	50·26	2·78	1·68	15·29	30·51	45·80

to chemical composition the average American hays are all much richer in protein, somewhat richer in ether extract and contain less ash than the Indian hays shown in the table. It is only fair to say that richer Indian hays exist, but the figures quoted here appear to be fair average samples (Pusa Bull. No. 70). The digestibility of the hay used at Bangalore is somewhat higher than American Prairie hay, but it is much inferior to the better class of American hays. The net energy value of our hay will therefore be lower than that of average American hays. It is worth recollecting at this point that our bullocks on rice straw attained a superior digestion to that found in America. This would indicate that our hay is somewhat poorer than the comparison with American figures shows it to be.

3. *Estimation of net energy values.* During two periods, namely, from April 5th to June 13th and from August 2nd to November 14th, the six animals were fed quantitatively. The food consumption was regulated as far as possible and accurately determined and live weights were taken daily. From these figures the weekly average live weight and the daily average food consumption for the week were found. The results of these records are shown in charts 1—4 below.

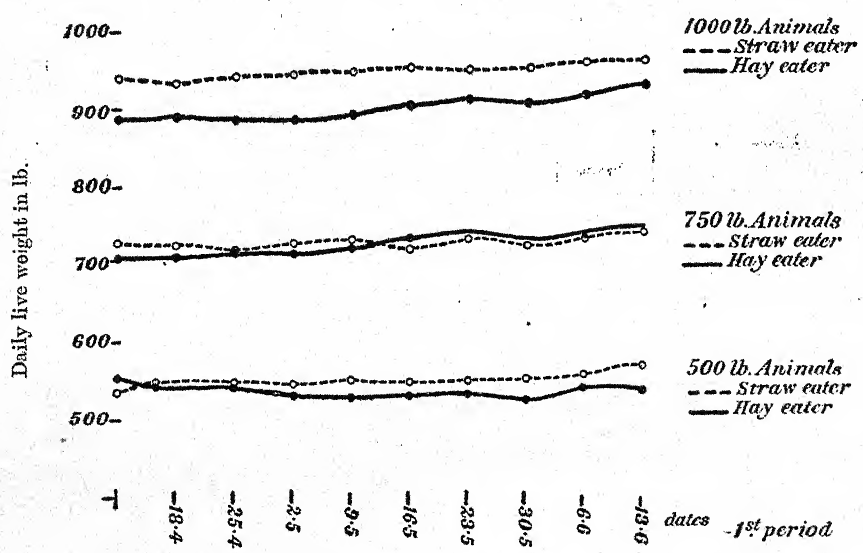


CHART 1.

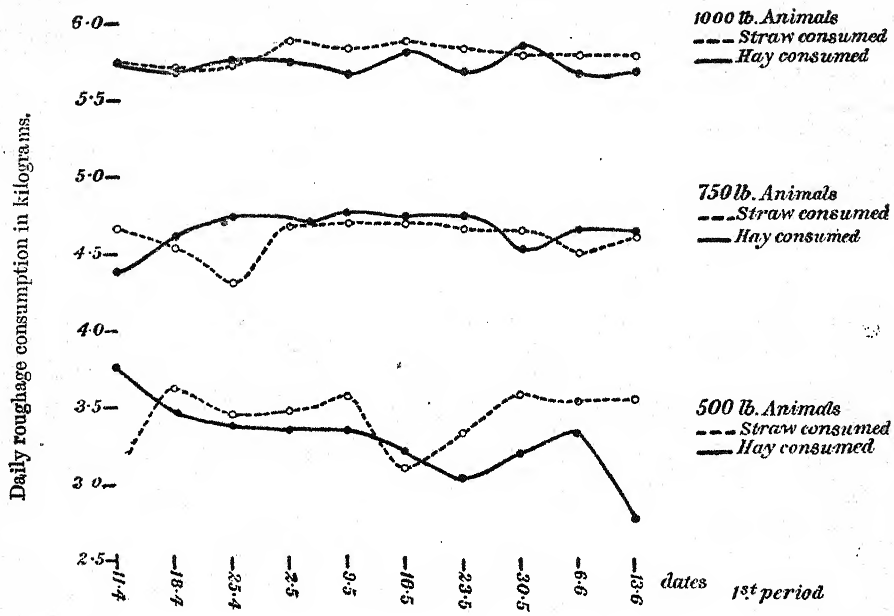


CHART 2.

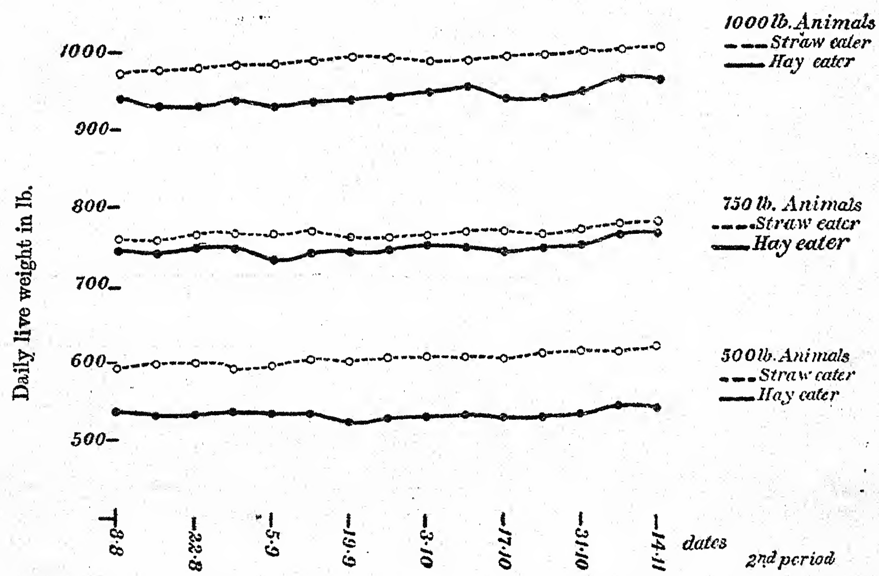


CHART 3.

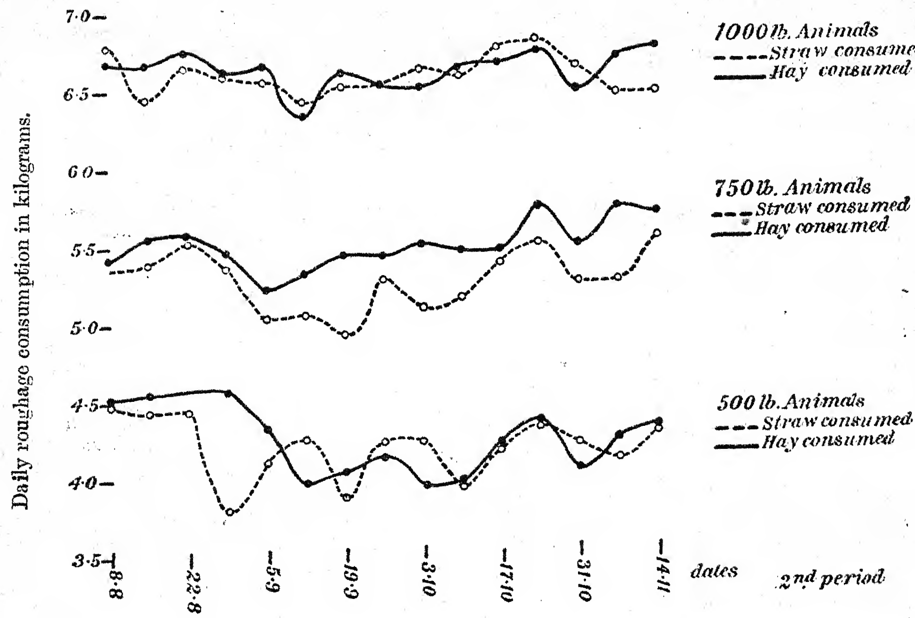


CHART 4.

The circumstances connected with these tests have been noted already. Both experiments had to be cut short and in the first experiment the ration was not suitable. The data are therefore not altogether satisfactory, but they will be treated, nevertheless, as had been intended when the experiment was initiated. From the charts and daily records the information in Table VII has been derived.

TABLE VII.

Data relating to the quantitative feeding tests.

	—		1,000 lb. animals		750 lb. animals		500 lb. animals	
			No. 1 Straw	No. 2 Hay	No. 3 Straw	No. 4 Hay	No. 5 Straw	No. 6 Hay
1st test.	Average live weight.	lb.	950·5	910·5	734·0	730	555	542·5
	Average daily live weight increase	lb.	·5	·8	·33	·5	·32	—·16
	Daily concentrate consumption	lb.	3·3	3·3	2·75	2·75	2·20	2·20
	" roughage consumption	lb.	12·90	12·80	10·27	10·48	7·66	7·44
2nd test.	Average live weight	lb.	993	944	767	749	607	535
	Average daily live weight increase	lb.	·31	·31	·24	·19	·20	·10
	Daily concentrate consumption	lb.	1·58	1·58	1·32	1·32	1·10	1·10
	" roughage consumption	lb.	14·45	14·54	11·57	12·08	9·28	9·33

[The average daily live weight increases were found from the slope of the smoothed live weight curves.]

This table is a condensed summary of the two feeding tests. The actual nutritive effect of the rations consumed is shown by these figures. Clearly also the figures contain definite information regarding the nutritive values of the two roughages, but the data as they stand are too seriously complicated by differences in live weight and differences in live weight increase to be of practical use. To reduce the results to a working common basis, the following process has been employed. The net energy theoretically required to produce the observed nutritive effect has been calculated from Armsby's feeding standard (using 6 Therms per 1000 lb. as the maintenance requirement and 3 Therms as the requirement per lb. increase.) This figure gives the total net energy provided by the ration. The net energy provided by the concentrate is accurately known. Hence, by difference, the net energy of the roughage is found. During the first test the animals were regularly exercised. A rough correction for net energy spent on exercise has to be included in the first test. During the second test the exercise was reduced to a negligible quantity. The animals were kept in condition mainly by changes in position, being tied outside for part of the day. The calculations are shown in the accompanying table.

TABLE VIII.

Estimation of net energy values of rice straw and hay.

	Daily	Straw eaters			Hay eaters		
		1,000 lb. animal No. 1	750 lb. animal No. 3	500 lb. animal No. 5	1,000 lb. animal No. 2	750 lb. animal No. 4	500 lb. animal No. 6
1st Test	Therms. Net energy required for maintenance.	5·80	4·85	4·00	5·60	4·83	3·96
	" Net energy expended in exercise.	·24	·18	·12	·24	·18	·12
	" Net energy required for live weight increase.	1·50	1·05	·99	2·40	1·00	—·50
	" Total net energy obtained from ration.	7·54	6·08	5·11	8·24	6·01	3·58
	" Net energy of concentrate .	3·09	2·57	2·06	3·09	2·57	2·06
	" Net energy from roughage .	4·45	3·51	3·05	5·15	3·44	1·52
	Lb. Roughage consumed . . .	12·98	10·27	7·66	12·80	10·48	7·44
	Net energy value of roughage per 100 lb.	34·3	34·4	39·8	40·2	32·8	20·0*
2nd Test	Therms. Net energy required for maintenance.	6·00	5·02	4·26	5·89	4·92	3·92
	" Net energy required for live weight increase.	·93	·72	·66	·93	·60	·30
	" Total net energy obtained from ration.	6·93	5·74	4·92	6·73	5·52	4·22
	" Net energy of concentrate .	1·47	1·22	1·02	1·47	1·02	1·02
	" Net energy from roughage .	5·46	4·52	3·90	5·26	4·30	3·20
	Lb. Roughage consumed. . :	14·45	11·57	9·28	14·54	12·08	9·33
	Net energy value of roughage per 100 lb.	37·7	39·0	42·0	36·2	35·8	34·3†

* This low figure is doubtless due to the fact that the animal was suffering from nasal granuloma.

† As the animal's state of health was probably abnormal, this result has been excluded in calculating the net energy value of hay.

The net energy values found in this way are undoubtedly significant as relative values for our straw and hay respectively. They show that the two roughages are approximately equal, the rice straw probably possessing a slightly higher value. The absolute values found by such a process are liable to be affected by serious errors. Some of these sources of error are well illustrated by comparing the two tests. Without claiming great reliability for the second test there is no doubt that it is more trustworthy than the first test. To begin with, the second test was carried out for a much longer period and hence the estimated gains during this test are more reliable. Secondly, the gains made during the second test were much smaller and therefore errors due to a wrong estimate for the net energy values of the gains are correspondingly reduced in the second test. Thirdly, the amount of concentrate fed was much lower in the second test. In this way a much larger proportion of the total net energy was provided by the roughage and the percentage error was thereby very materially reduced. Fourthly, the doubtful correction for exercise has been avoided in the second test. For these reasons the first test will be left out of account altogether. As mentioned already it has only been included to make the record of the work complete.

As far as the second test can be relied upon it shows that the net energy values of rice straw and hay are 40 Therms and 36 Therms per 100 lb. respectively (or 44 Therms and 39·6 Therms per 100 lb. dry substance). It may be stated at once that these figures differ entirely from Armsby's values. For rice straw the Bangalore feeding test figure is 17 Therms higher, for hay it is 12 Therms lower than Armsby's value. The largest item on which the Bangalore calculation is based is the net energy required for maintenance. For this purpose, Armsby's average of 6 Therms per 1,000 lb. live weight was used. This requirement is not absolutely constant and may vary considerably in certain cases. Values ranging from 5 to 7 Therms are quoted in the literature. It is important to note what effect such variations would have on the calculated net energy. In the next table the net energy of the roughages has been calculated exactly as above but making different allowances for the maintenance requirement.

TABLE IX.

Calculated net energy of roughages using different values for the maintenance requirement.

Assumed net energy for maintenance	Estimated net energy of rice straw			Estimated net energy of hay		
	No. 1	No. 3	No. 5	No. 2	No. 4	No. 6
5 Therms	30·8	31·8	34·4	29·5	28·8	27·3
6 "	37·7	39·0	42·0	36·2	35·8	34·3
7 "	54·9	56·9	60·6	53·0	52·6	52·2

These figures make one point quite clear. It is certain that there were no marked differences in the maintenance requirements of our six bullocks. The figures of one line cannot be mixed up with any of the figures on another line. There is no such variation for maintenance requirement amongst these six bullocks as 5 to 6 or 6 to 7 Therms. This is a very definite result which shows that the net energy values in one of the lines of the table above must roughly represent the actual net energy values of the two food stuffs. It has already been noted that the calculated result for rice straw based on 6 Therms for maintenance is much higher than Armsby's result and it can only be reduced by assuming a lower maintenance requirement. It is seen now that an allowance of 5 Therms still leaves the value for rice straw too high, whilst it brings down the hay value to an incredibly low level. It has to be concluded therefore that a closer agreement cannot be attained by using any other than Armsby's average maintenance allowance of 6 Therms.

Light is thrown on these anomalous results by examining the digestibility figures in the first part of this paper. It will be seen there that rice straw in America has been found to yield 42 lb. of digestible organic matter from 100 lb. of dry substance, whilst at Bangalore 49·9 lb. were obtained as an average. That is to say, a higher digestion has been attained and a correspondingly higher net energy value has to be assigned to the Bangalore rice straw. A chart published by the writer a short time ago in the *Agricultural Journal of India* shows how the net energy value may be estimated roughly from the figure for digestible organic matter. The net energy value of Bangalore rice straw estimated in this way is found to be 40 Therms per 100 lb. dry substance. The corresponding figure for Bangalore hay obtained from the graph is 39 Therms. In the case of our Bangalore rice straw it is possible to calculate the net energy value by Armsby's method. The result calculated in this way is 38 Therms. A similar calculation for our hay cannot be made. The results obtained by the different processes are tabulated here for comparison.

TABLE X.

Net energy values in therms per 100 lb. dry substance.

—	Estimated by Armsby's method	Estimated from graph in *Agricultural Journal of India*	Estimated from the feeding experiments*
Bangalore rice straw . .	38	40	44
Bangalore hay . . .	?	39	39·6

*Using 6 Therms for maintenance.

These figures corroborate one another and leave no doubt that the net energy value of our rice straw is higher than the figures given for American rice straw (namely 25 Therms per 100 lb. dry substance). It is equally certain that our hay is poorer than average American hay. It will be noticed that, in the case of rice straw, the feeding test gives a higher net energy value than the graphic method, whilst for hay the two sets of figures are nearly the same. Now the graph represents the average relationship between digestibility and net energy value, and the actual net energy value may be more or less than this amount. If the feeding test is to be of real use it must do more than the graph. It must show the direction in and extent to which the actual net energy value deviates from this average.

For reasons already given the feeding test results obtained above are not considered sufficiently accurate to enable us to affirm that the true net energy value of our rice straw is really greater than the graphic figure. But the feeding test can be made more accurate by adjusting the ration to give smaller live weight increases, by prolonging the test to make the determination of live weight increments more accurate and by using more animals to eliminate the error due to variations in the metabolism of individuals. It is proposed to carry out further tests on these lines at Bangalore in conjunction with digestion experiments. One more point deserves notice. The agreement between the graphic and feeding results has another significance. It shows that the net energy requirements of our bullocks approximate very closely to Armsby's average of 6 Therms per 1,000 lb. live weight. This is an important result.

The Nitrogen balance in relation to rate of growth. Table XI shows the nitrogen balances which were found during the three digestion experiments.

TABLE XI.

Nitrogen balance in relation to live weight increase.

—		1,000 lb. animals		750 lb. animals		500 lb. animals	
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
1st test.	Average daily nitrogen balance in grm.	17·9	15·2	7·2	13·2	9·9	15·66
	Average daily live weight increase in lb.	·50	·70	·33	·50	·50	·25
2nd test.	Daily nitrogen balance.	15·7	11·2	6·9	5·8	9·1	6·1
	" " "	9·1	9·7	6·5	6·8	6·9	6·4
	Average daily nitrogen balance in grm.	12·9	10·5	6·7	6·3	8·0	6·3
	Average daily live weight increase in lb.	·31	·31	·24	·19	·20	·10

The first set of figures was determined during the period of high protein feeding and is referred to the average rate of live weight increase found during the first test. During the second test the nitrogen balance was determined twice. The average of these two results is referred to the daily live weight increase during the second period. The balance was positive in every case, but it cannot be said that there is any close parallelism between the nitrogen balance and the live weight increase. It has to be concluded therefore that with these bullocks the nitrogen balance determined from 6 to 8 days of continuous sampling is not an accurate index of the average live weight increase during the long period feeding test.

4. *The physiological effect of the ration.* The striking physiological fact brought to light by this feeding test is that rice straw induces a marked and persistent diuresis. The following table shows the average daily urine, nitrogen and potash excretion during three periods of the experiment.

TABLE XII.

Average excretion of urine, nitrogen and potash.

——	1,000 lb. animals		750 lb. animals		500 lb. animals	
	No. 1 Straw	No. 2 Hay	No. 3 Straw	No. 4 Hay	No. 5 Straw	No. 6 Hay
Average daily urine excretion in kilos.—						
1st test. April 1925	7·871	3·947	7·797	3·665	6·299	3·219
2nd test. September 1925	6·830	2·842	5·877	3·021	4·968	3·141
3rd test. November 1925	7·572	3·329	7·223	3·338	5·745	2·563
Average	7·091	3·373	6·966	3·341	5·671	2·974
Average daily nitrogen excretion in urine in grm.—						
1st test. April 1925	90·58	91·74	81·82	75·20	63·00	55·48
2nd test. September 1925	37·36	35·83	37·83	35·25	27·83	26·34
3rd test. November 1925	38·45	36·93	37·86	32·09	26·14	22·77
Average daily potash excreted in urine in grm.—						
1st test. April 1925	92·50	33·14	83·77	27·11	61·43	20·14
2nd test. September 1925	100·30	31·50	92·20	26·30	67·13	21·53
3rd test. November 1925	130·58	33·50	119·53	31·27	90·07	22·21
Average	107·79	32·71	98·50	28·23	72·88	21·29

In every case the rice straw animals excreted much more urine than the corresponding hay fed animals. It will be observed too that the amount of urine excreted is practically independent of the nitrogen excretion. The high nitrogen excretion

during the first test is due to the large proportion of protein in the ration at that time. Less protein was given and hence less nitrogen was excreted during the second and third tests. The figures show that a reduction of the urinary nitrogen to less than half its initial amount caused no appreciable change in the volume of urine excreted. The straw fed animals always urinated more profusely. The third series of figures giving the daily potash excreted in the urine shows that the diuresis is intimately related to potash excretion.

Table XIII gives the concentration of potash and total nitrogen in the urine.

TABLE XIII.

Concentration of potash and nitrogen excreted in urine.

—	1.000 lb. animals		750 lb. animals		500 lb. animals	
	Straw	Hay	Straw	Hay	Straw	Hay
Concentration of potash in grm. per Kilo urine.—						
1st test	11·80	8·40	10·74	7·40	9·75	6·26
2nd "	14·68	11·08	15·69	8·71	13·51	6·86
3rd "	17·25	10·06	16·54	9·37	15·68	8·67
Concentration of nitrogen in grm. per Kilo urine.—						
1st test	12·33	23·24	10·50	20·52	10·00	17·24
2nd "	5·47	12·61	6·44	11·67	5·60	8·39
3rd "	5·08	11·09	5·24	9·61	4·55	8·88

These figures show once more that the nitrogen concentration may vary between 12 and 5 or between 23 and 11 grm. per litre. That is to say, within these limits the volume of urine is unaffected by the amount of nitrogen excreted. Potash, on the other hand, clearly must be eliminated in moderately dilute solution. The figures, however, indicate another interesting point, namely, that the straw eating animals gradually developed a tolerance for potash and were able to eliminate it in steadily increasing concentration as the feeding test progressed.

For the source of this excreted potash we have to examine the foodstuffs. The potash content of the food fed during the digestion experiments is given in the accompanying table.

Table XIV.

Potash in grm. per 100 grm. dry substance.

—	1st test	2nd test	3rd test
Groundnut cake	1·499	1·446	1·398
Rice straw	1·689	1·665	2·280
Hay	·590	·524	·629

From these figures the daily amount of potash ingested has been calculated. The figures are given in the next table.

Table XV.

Total potash ingested with food in grams per day.

No. of animal	Food	1st test		2nd test		3rd test	
		Dry matter consumed grams	Potash in dry matter grams	Dry matter consumed grams	Potash in dry matter grams	Dry matter consumed grams	Potash in dry matter grams
Straw eaters—							
No. 1	Roughage	5179·5	87·49	5854·0	97·47	5665·3	129·15
	Concentrate	1380·0	20·68	665·3	9·62	666·7	9·32
	Total	6559·5	108·17	6519·3	107·09	6332·0	138·47
No. 3	Roughage	4168·8	70·41	4573·0	76·14	4829·3	110·10
	Concentrate	1112·3	16·67	554·4	8·02	555·6	7·77
	Total	5281·1	87·14	5127·4	84·16	5384·9	117·87
No. 5	Roughage	3075·8	49·61	3599·0	58·92	3616·0	85·98
	Concentrate	920·1	13·79	462·0	6·67	462·0	6·47
	Total	3995·9	63·40	4061·0	65·59	4078·0	92·45
Hay eaters—							
No. 2	Roughage	5106·0	30·13	5839·0	30·60	5952·9	37·44
	Concentrate	1380·0	20·68	665·3	9·62	666·7	9·32
	Total	6486·0	50·81	6504·3	40·22	6619·6	46·76
No. 4	Roughage	4240·3	25·02	4809·0	25·20	4940·1	31·07
	Concentrate	1143·6	17·27	554·4	8·02	555·6	7·77
	Total	5383·9	42·29	5363·4	33·22	5495·7	38·84
No. 6	Roughage	2980·7	17·59	3616·0	18·95	3775·4	23·75
	Concentrate	907·0	13·60	462·0	6·67	463·0	6·47
	Total	3887·7	31·19	4078·0	25·62	4238·4	30·22

We are now in a position to compare the potash ingested with potash excreted in the urine. This comparison is made in Table XVI.

TABLE XVI.

Comparison of potash ingested and potash excreted in urine.

Animal No.	Test	Straw eaters			Animal No.	Test	Hay eaters		
		Potash consumed grams	Potash in urine grams	Volume of urine Litre			Potash consumed grams	Potash in urine grams	Volume of urine Litre
No. 1	1st	108·2	92·5	7·87	No. 2	1st	50·8	33·1	3·95
	2nd	107·1	100·3	6·83		2nd	40·2	31·5	2·84
	3rd	138·5	130·6	7·57		3rd	46·8	33·5	3·33
No. 3	1st	87·1	83·8	7·80	No. 4	1st	42·3	27·1	3·67
	2nd	84·2	92·2	5·88		2nd	33·2	26·3	3·02
	3rd	117·9	119·5	7·22		3rd	38·8	31·3	3·34
No. 5	1st	63·4	61·4	6·30	No. 6	1st	31·2	20·1	3·22
	2nd	65·6	67·1	4·97		2nd	25·6	21·5	3·14
	3rd	92·5	90·1	5·75		3rd	30·2	22·5	2·56

This table shows that when the amount of potash ingested is high, as in the case of the straw eaters, almost all of it is excreted in the urine. When the amount ingested is low, a high proportion of it is still excreted in the urine but an appreciable fraction remains to be excreted in the fæces. It may be noted here, too, that while the amount of urine is mainly dependent upon the potash, there is another subsidiary factor at work. Its nature has not been established yet.

Subsidiary tests. To obtain further information on the subject of diuresis two subsidiary experiments were carried out on the termination of the main feeding experiment. In the first of these experiments potash was administered to the hay animals per os to bring their potash excretion up to that of the straw eaters. The drench (a mixture of potassium carbonate and acetate) was given in small amounts four times a day to distribute the effect as much as possible. The results of this experiment are given in Tables XVII*a* and XVII*b*.

TABLE XVIIa.

Excretion of urine, nitrogen and potash before and after administration of potash salts.

—		1,000 lb. ANIMALS		750 lb. ANIMALS		500 lb. ANIMALS	
		Straw	Hay	Straw	Hay	Straw	Hay
Average daily urine excretion 11th November 1925 to 13th November 1925.	Kilos.	7·572	3·329	7·223	3·338	5·745	2·563
Potash administered daily from 14th November 1925 to 17th November 1925.	Grm.	..	63·34	..	52·78	..	42·23
Average daily urine excretion 15th November 1925 to 17th November 1925.	Kilos.	8·075	6·197	6·909	4·971	6·939	4·249
Average daily nitrogen excretion in urine—							
11th November 1925 to 13th November 1925.	Grm.	38·45	36·93	37·86	32·09	26·14	22·77
15th November 1925 to 17th November 1925.	,,	43·65	42·83	36·06	34·67	28·74	28·69
Average daily potash excretion in—							
11th November 1925 to 13th November 1925.	Grm.	120·70	36·83	121·23	31·27	82·70	22·21
15th November 1925 to 17th November 1925.	,,	140·50	90·07	117·83	57·23	97·43	54·40

TABLE XVIIb.

Concentration of nitrogen and potash in urine before and after administration of potash.

—	1,000 lb. ANIMALS		750 lb. ANIMALS		500 lb. ANIMALS	
	Straw	Hay	Straw	Hay	Straw	Hay
Concentration of nitrogen in grm. per kilo urine—						
11th November 1925 to 13th November 1925.	5·13	11·09	5·24	9·61	4·55	8·88
15th November 1925 to 17th November 1925.	5·41	6·91	5·22	6·98	4·14	6·75
Concentration of potash in grm. per kilo urine—						
11th November 1925 to 13th November 1925.	15·94	11·06	16·78	9·37	14·40	8·67
15th November 1925 to 17th November 1925.	17·40	14·54	17·05	11·51	14·04	12·80

The administration of potash considerably increased the urination of Nos. 2 and 6. The effect on No. 4 was less marked. In no case, however, did the urination reach the figures of the straw eaters. There are two reasons for this. In the first place, the administered potash was retained to a considerable extent, although the drenching was begun 24 hours before the collection of urine commenced. The table shows that for three days the average retention of potash given in the drench amounted to 10 grm., 26·9 grm. and 10 grm. for numbers 2, 4 and 6 respectively.

The potash excretion having been moderated by this retention the diuresis was less severe than anticipated. It will be noticed also that No. 4 animal whose urination was least affected by the drench retained an abnormally high proportion of the administered potash. Secondly, the rice straw was unusually rich in potash during the experiment. This fact was not known at the time and the drench did not provide an equivalent amount. Table XIV*b*, giving potash concentration of the urine shows that during rapidly induced diuresis by administration of potash the concentration of this base in the urine remains lower than that found with animals which have become accustomed to daily excessive elimination.

In the second experiment the straw animals were brought on to a hay ration as quickly as possible. It took a fortnight to accomplish this. The urination of all six animals on a hay ration was determined then for three days. The results of this test are given in Table XVIII.

TABLE XVIII.

Urine excretion after putting all the animals on the same roughage (Hay).

—	1,000 lb. ANIMALS		750 lb. ANIMALS		500 lb. ANIMALS	
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Average roughage consumed in Kilos per day.	6·804	6·790	5·359	5·301	4·520	3·994
Daily urine excretion in Kilos, Dec. 4th	4·175	3·465	4·078	3·815	2·633	3·145
,, 5th	4·135	3·350	2·610	3·053	2·425	3·795
,, 6th	3·905	2·935	3·843	2·420	2·742	2·520
Average	4·072	3·250	3·510	3·096	2·600	3·153

The figures show that the urination of the straw eaters Nos. 1, 3 and 5 had become practically normal a fortnight after the change of ration.

Total mineral excretion. Table XIX gives the daily excretion of minerals during the three tests.

TABLE XIX.

Average daily excretion of minerals in urine (in grm.).

—	1,000 lb. ANIMALS		750 lb. ANIMALS		500 lb. ANIMALS	
	No. 1 Straw	No. 2 Hay	No. 3 Straw	No. 4 Hay	No. 5 Straw	No. 6 Hay
First test, April 1925—						
P_2O_5	·20	·14	·17	·08	·25	·06
CaO	10·68	10·56	5·85	12·46	·74	4·99
Mgo	2·17	3·64	2·48	1·13	1·53	1·20
SO_3	6·75	4·76	5·59	4·24	4·36	3·52
Na_2O	27·91	4·20	26·84	5·55	25·93	7·22
K_2O	92·50	33·14	83·77	27·11	61·43	20·14
TOTAL	140·21	56·44	124·70	50·57	94·24	37·13
Second test, September 1925—						
P_2O_5	·29	·11	·14	·09	·14	·07
CaO	·56	·66	·60	8·01	·23	2·84
Mgo	9·10	6·04	4·66	6·06	3·14	3·14
SO_3	3·34	2·51	3·09	2·09	2·23	..
Na_2O	31·30	6·88	13·72	5·51	26·02	6·80
K_2O	100·28	31·50	92·20	26·28	67·12	21·53
TOTAL	144·87	47·70	114·41	48·24	98·88	34·38
Third test, November 1925—						
P_2O_5	·21	·08	·12	·08	·18	·07
CaO	·49	6·41	·68	6·65	·25	3·76
Mgo	8·29	8·33	4·41	7·69	3·74	5·07
SO_3	5·37	2·80	4·86	3·03	3·43	2·00
Na_2O	43·80	3·13	41·92	3·00	32·20	31·38
K_2O	130·58	33·50	119.53	31·27	90·07	22·21
TOTAL	188·74	54·25	171·52	51·72	129·87	64·49

These figures show clearly that only the potash can be held responsible for the diuresis. Other noteworthy points are the following :—

A relatively high soda excretion is invariably associated with high potash excretion. The very low soda excretion by the hay animals is remarkable. The amounts excreted in the urine do not account for half the sodium chloride ration without considering the sodium present in the foodstuffs. It was found with these animals that they excreted more sodium in the fæces than in the urine which is a remarkable phenomenon. No. 6 behaved peculiarly in the last test, but we know

that this animal's metabolism was not normal. The only other figures which show regularity are the figures for P_2O_5 which are quite uniformly very low with all the animals. There are some extraordinary variations in the figures for lime and magnesia. No explanation is offered for these peculiarities at present. As a check on the figures for mineral excretion the amount of silica free ash digested during the digestion experiments is useful. In Table XX the digested mineral matter is compared with the excreted minerals.

Table XX.

Comparison of soluble ash digested (during digestion experiments) with total minerals excreted in urine.

The NaCl fed separately is not included in these figures.

—	1,000 lb. animals		750 lb. animals		500 lb. animals	
	No. 1 Straw	No. 2 Hay	No. 3 Straw	No. 4 Hay	No. 5 Straw	No. 6 Hay
First test, April—						
Excreted in urine	140·2	56·4	124·7	50·6	94·2	37·1
Digested	151·2	64·6	118·3	64·3	77·5	39·4
Difference	+11·0	+8·2	—6·4	+13·7	—16·7	+2·3
Second test, September—						
Excreted in urine	144·9	47·7	114·4	48·2	98·9	34·4
Digested	157·3	81·5	108·2	63·2	100·6	50·7
Difference	+12·4	+33·8	— 6·2	+15·0	+1·7	+16·3
Third test, November—						
Excreted in urine	188·7	54·2	171·5	51·7	129·9	64·5*
Digested	—171 3	78·2	158·4	76·6	116·8	50·45
Difference	—17·4	+24·0	—13·1	+24·9	—13·1	?

* Contains an abnormal amount of Na Cl. Table XIX.

It would appear from these results that the hay animals assimilated more minerals than the straw animals.

The effect of high urination upon the faeces. The effect of high urine excretion upon the moisture content of the fæces is worth remarking upon. Table XXI shows the amount of water excreted in the faeces and urine respectively.

TABLE XXI.

Total water excreted in urine and faeces.

—	1,000 lb. ANIMALS		750 lb. ANIMALS		500 lb. ANIMALS	
	Straw	Hay	Straw	Hay	Straw	Hay
1st test, April—						
Average water in fæces	9·502	12·125	7·380	9·363	6·196	8·869
Average water in urine	7·467	3·576	7·446	3·357	6·028	3·001
TOTAL WATER	16·969	15·701	14·826	12·720	12·224	11·870
Second test, September—						
Average water in fæces	9·947	12·317	8·469	8·649	6·087	8·556
Average water in urine	6·462	2·543	5·537	2·771	4·729	2·967
TOTAL WATER	16·409	14·860	14·006	11·420	10·816	11·523
Third test, November—						
Average water in fæces	9·443	10·560	8·134	9·408	6·180	9·013
Average water in urine	7·149	3·046	6·933	3·093	5·448	3·383
TOTAL WATER	16·592	13·606	15·067	12·501	11·628	12·396

It is seen that almost without exception high urination results in less moist fæces. This may be, of course, only a coincidence, the real fact being that hay fæces are more moist than straw fæces. At present, we have no data for solving this question. It should be mentioned that the animals were provided with water *ad lib.*

Nitrogen distribution in urine. The figures in the accompanying table are averages of two or three days' determinations which did not agree very closely.

TABLE XXII.

Nitrogen distribution in urine. (Average daily excretion of nitrogen in grm.)

—	1,000 lb. ANIMALS		750 lb. ANIMALS		500 lb. ANIMALS	
	Straw	Hay	Straw	Hay	Straw	Hay
First test, May 1925—						
Total nitrogen	97·46	91·18	82·15	74·92	65·73	60·18
Urea and ammonia	79·59	67·07	68·83	56·39	56·04	47·19
Creatinin and creatinin	4·52	2·69	3·27	2·33	2·38	2·23
Amino acid nitrogen	3·92	5·91	3·99	5·43	2·82	3·84
Undetermined	9·43	15·52	6·06	10·77	4·49	6·92

Nitrogen distribution in urine. (Average daily excretion of nitrogen in grm.) —contd.

—	1,000 lb. ANIMALS		750 lb. ANIMALS		500 lb. ANIMALS	
	Straw	Hay	Straw	Hay	Straw	Hay
Second test, September 1925—						
Total nitrogen	35·76	38·33	39·19	36·25	28·79	28·50
Urea and ammonia	19·47	20·44	25·60	20·70	17·66	16·21
Creatinin and creatinin	4·00	2·92	3·06	2·49	2·57	2·08
Amino acid nitrogen	5·01	4·90	4·30	3·87	2·37	4·81
Undetermined	7·28	10·07	5·23	9·19	6·19	5·40
Third test, November 1925—						
Total nitrogen	38·29	36·97	37·82	32·20	25·92	22·73
Urea and ammonia	20·81	18·27	22·94	16·69	14·68	10·89
Creatinin and creatinin	4·72	3·49	3·66	2·99	3·13	2·18
Amino acid nitrogen	4·65	8·16	3·56	5·31	3·85	6·14
Undetermined	8·11	7·05	7·66	7·21	4·26	3·52
Fourth test, November 1925—						
Total nitrogen	43·69	42·71	35·89	34·11	28·61	28·51
Urea and ammonia	26·25	25·57	22·88	19·27	18·30	17·00
Creatinin and creatinin	4·95	3·78	3·43	3·06	3·17	2·53
Amino acid nitrogen	3·48	3·65	3·28	3·33	2·26	2·55
Undetermined	9·01	9·71	6·30	8·45	4·88	6·43

It seems clear that the straw eaters eliminated more creatine and creatinine. Generally they eliminated less hippuric acid, but in this case there are some irregularities. At this stage of the work nothing can be said regarding the significance of these figures.

Coat colour. Of the animals tested the first four have a beautiful black coat with white markings, the two last are white. At the end of the feeding test the animals were examined by several visitors. The two lots could not be distinguished from one another in condition, skin, or brightness, but the coat colour of the black and white straw eaters had become lighter than that of their mates. Since this observation the animals have been on mixed rations and the coats of the four have become alike again.

The significance of potash diuresis. It is impossible to say, at present, what the effect of this diuresis will be. Up to a point the elimination of urine is a healthy symptom. It may be expected to clear the system. On the other hand, the excretion of very large amounts of urine, or of urine of abnormal reaction, is a strain

on the kidneys and must inevitably lead to serious results. It is possible that a subject of fundamental importance to animal nutrition in India has been met with here. The question is being followed up tentatively at present.

Summary.

1. Accurate digestion data have been obtained for rice straw and baled hay. It has been found that our rice straw is more completely digested by our bullocks than American rice straw by American bullocks. This difference is to be attributed to the digestive capacity of our animals rather than to the quality of the foodstuff. Considering the results obtained with rice straw the quality of our hay (Bolarum Rukh Hay) must be considered disappointing. Even with our bullocks it was found to be inferior to average American hay.

2. The net energy values of the two roughages have been determined indirectly from feeding experiments. The results so found agree as well as could be expected with figures obtained by the writer's graphic method, but they diverge considerably from accepted American values.

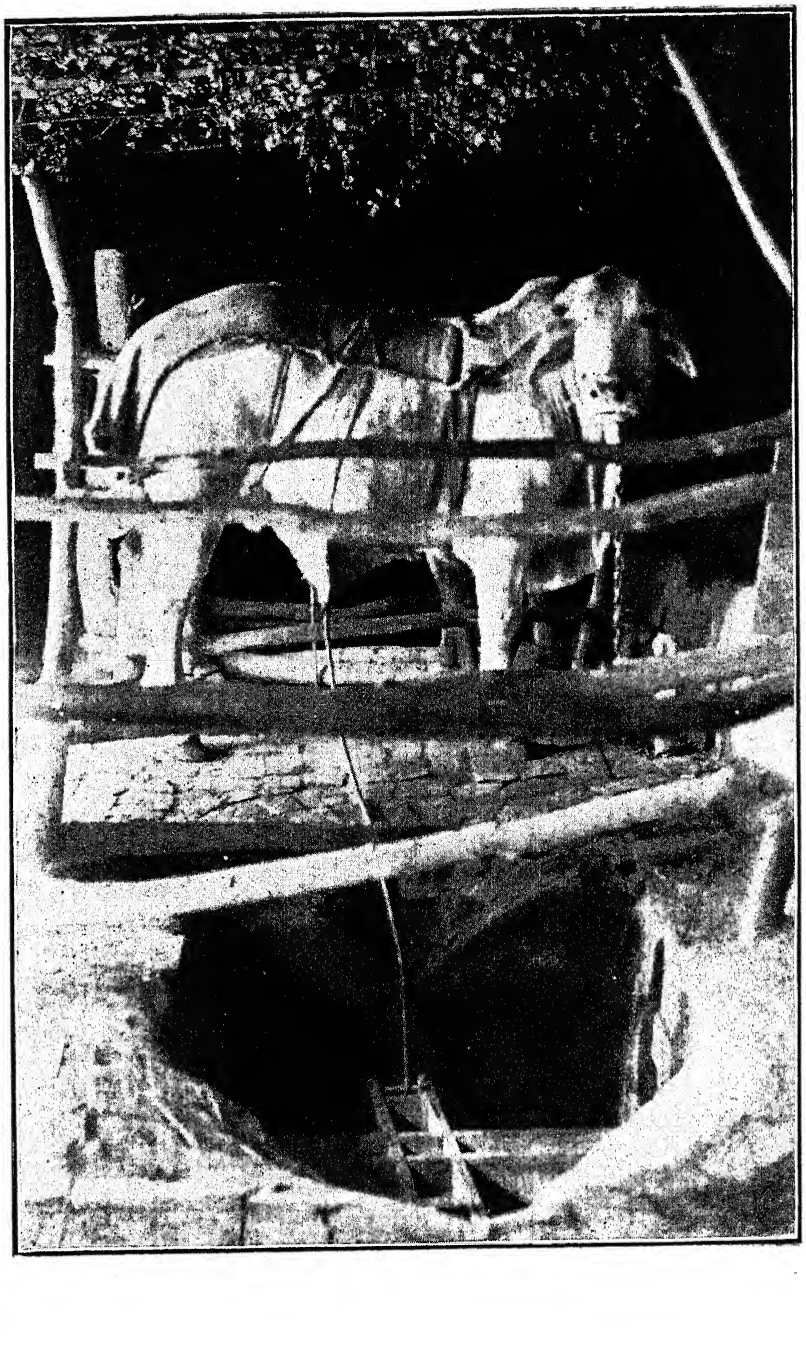
3. Reasoning from the net energy value data it is concluded that the maintenance requirement of our bullocks must approximate fairly closely to Armsby's average value of 6 Therms per 1,000 lb. live weight. This is a valuable piece of information.

4. From the physiological point of view it has been found that rice straw induces diuresis, and the cause of the diuresis has been traced to the high potash content of the straw. This observation may possibly be of considerable significance to Animal Nutrition in India. Further study of the subject is desirable.

Acknowledgments. I have to acknowledge, with thanks, the splendid work done by the members of my staff who carried out all the analyses connected with this enquiry.

MGIPC—M—IV-2-39—3-1-27—600.

PLATE I.



ERRATUM.

For " Bolarum " on page 61, Chemical Memoir, Vol. IX, No. 2, under Summary, fifth line.

Read " Bellary".

SOME DIGESTIBILITY TRIALS ON INDIAN FEEDING STUFFS, II.

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In a previous paper[1], an account was given of some digestibility trials carried out at Lyallpur during the cold weathers of 1921-22 and 1922-23, with Bhusa, gram (*Cicer arietinum*), maize (*Zea Mays*), and fresh Shisham (*Dalbergia Sissoo*) leaves, the object being to determine the quantitative feeding values and the digestibilities of those diets in order to determine how far Shisham leaves could be utilized as a fodder reserve.

It was pointed out that fresh Shisham leaves could be taken by the animals under trial only in very limited quantity, owing to the disturbing effect which they had on the digestive tract when fed in large quantities.

It was therefore thought advisable to try the effect of siloing the Shisham leaves and feeding to animals, both alone, and in conjunction with other feeds.

Two sets of experiments were planned :—

(1) Digestibility trials on stall fed animals in which siloed Shisham was fed alone and in combination with Bhusa, and for comparison, a combination of green Sarson (*Brassica campestris*, var) and Bhusa was fed.

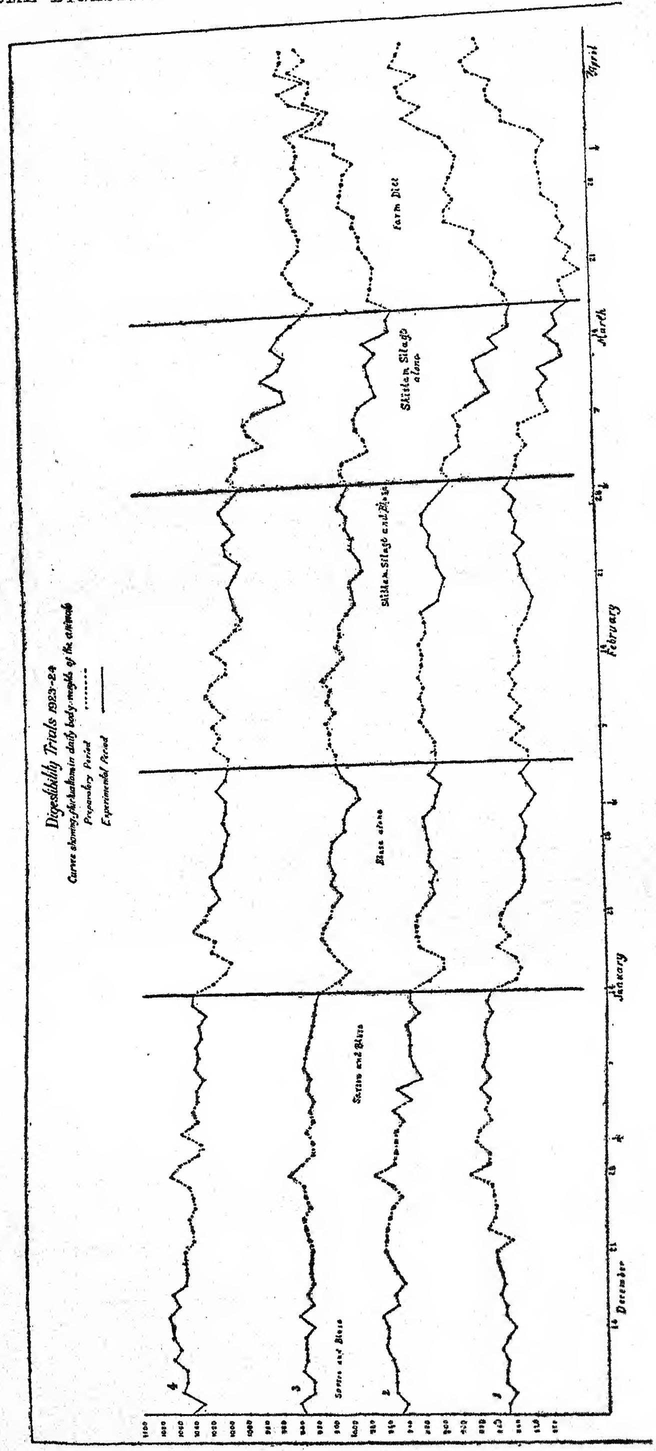
(2) Trials in which the green fodder of milch cows was replaced by siloed Shisham.

The results obtained from these latter trials have already been published[2] and it is proposed now to give some account of the digestibility trials.

In all, five different diets were employed, *viz.*, Bhusa and green Sarson ; Bhusa alone ; Bhusa and siloed Shisham leaves ; siloed Shisham leaves alone ; and an

[1] Lander, P. E., and Dharmani, Pandit Lal Chand. Some digestibility trials on Indian Feeding stuffs. *Mem. Dept. of Agri. India, Chem. Ser.*, Vol. VII, No. 4, September 1924.

[2] Lander, P. E., and Dharmani, Pandit Lal Chand. A new fodder (siloed Shisham leaves) for Dairy Cows. *Pusa Agri. Res. Inst., Bull.* No. 158 of 1925.


Digestibility Trials 1923-24
Curves showing fluctuations in daily body-weights of the animals
Preparatory Period
Experimental Period
December
January
February
March
April
Farm Diet
Sitalan Silage alone
Bhusa alone

ordinary farm diet at the end of the Shisham period which consisted of mixtures of green and dry fodders, such as senji (*Melilotus parviflora*), turnips (*Brassica Rapa*), mangels (*Beta Vulgaris Macrorrhiza*), cane (*Saccharum officinarum*) tops and oats (*Avena sativa*), together with two lb. of grain each evening.

Full particulars of these various diets are given in Table I.

The animals and their management.

Four Montgomery bullocks were employed, whose ages varied between four and five years, and which may be designated as animals 1, 2, 3, 4, were under trial from 1st December 1923 until 3rd April 1924 and were weighed daily throughout this period as recorded in the previous paper. A graphic record of their weights as obtained during the various dietary periods is given in Fig. I.

It was also decided to carry out some observations on the urine and its constituents.

Some modification of the stall accommodation, as recorded for the previous trials, was necessary, as it was desired to collect the urine from each animal during the experimental periods. In order to do this with as little loss as possible, four pens were constructed and 'walled' off from each other by fenced partitions. In the middle of each two of the 'pens', a space was left, in the centre of which a hole was dug sufficiently large to admit an attendant who could manipulate the two kerosine tins into which the urine was passed by means of a rubber tube passing over a pulley, which tube connected with a bag attached to the animal's sheath. The bag was made of water proof material and in order to save the rubber tube from being damaged by the animal sitting on it on a level floor, the floor was sloped towards the centre and towards the side of the pit; in this way the tube had free play over the pulley, and urine could pass into the receptacle in the pit even should the animal happen to be lying down. On account of the slope the animals soon acquired the habit of sitting on one side leaving the whole of the tube free.

Plate I shows the general structure of the urine pit which was found to be satisfactory as the animals did not urinate when sitting except on very rare occasions.

Since these trials were carried out the experience gained therein has resulted in the construction of an entirely new digestion stall which has been described in a separate paper.[1]

Common salt was always available and the animals were fed half the daily ration in the morning and half in the evening, they were also watered once at noon daily and once in the evenings in the stalls during the experimental periods and at the watering tank during the non-experimental period.

Careful watch was kept over the dung bags which were emptied morning and evening. The dung and the urine bags were only worn during the experimental periods, and no ill effects appeared to result from their use.

[1] Lander, P. E. Stalls and harness used in the study of nitrogen metobolism and nutritive value of cattle feeds. *Agricultural Journal in India*, Vol. XXI, Part V, September 1926.

The experimental periods during which full records were kept were always preceded by a non-experimental or preparatory period during which the animals were fed the succeeding diet in order to remove all effects of the preceding diet.

During the non-experimental periods, between the feeding of the various diets the animals were allowed to roam about in the fields with muzzles on their mouths to prevent them from eating anything other than the prescribed diet, and at night time they were housed in a shed with a level *kacha* floor.

The ages of the bullocks on the date at which the trials were commenced were as follows :—

No. 1	3 years 8 months.
No. 2	4 „ $3\frac{1}{2}$ „
No. 3	4 „ 4 „
No. 4	4 „ 8 „

Each of the feeding periods may be considered separately and the information that we obtain on their digestibilities as a whole noted, and the digestibilities of the individual constituents thereof. The weights and conditions of the animals will also be noted and compared.

First experimental period (Tables II and III).

The diet employed was green Sarson and Bhusa. This period really consisted of three sub-periods, (i) 6th-13th December, 8 days; (ii) 14th-20th December, 7 days; (iii) January 4th-13th, 10 days.

During the first sub-period each of the four animals ate on an average 24 lb. of Sarson and from 8-12 lb. of Bhusa per day and the lowest and highest recorded digestibility co-efficients for the combined diet were 48·54 and 55·68 respectively, the corresponding figures for the Sarson being 46·10 and 70·74 respectively. It will be noted that animal 3 which gave the highest figure for the Sarson also gave the highest for the combined diet.

In calculating the figures for the Sarson from the 'combined' figures, it was necessary, of course, to calculate from the digestibility co-efficients of the Bhusa and its constituents as found by actual determination in the second experimental periods.

From Table IV it will be noticed that in every case the ash and the protein, which are present in comparatively small quantities, show negative co-efficients which indicate that, taking into consideration the experimental error, the determinations of the figures for these small quantities are affected by influences from the digestive tract.

We notice correspondingly on working out the co-efficients for the individual constituents of the Bhusa in the combined diet that the ash and the protein also show small negative values, although very considerably diminished in magnitude,

indicating that the effect of the added Sarson is in the direction of greater utilization, and consequent diminution of error. Similar results were obtained in the previous year's experiments and are a very common feature of all such trials.

On comparing the individual co-efficients for the Bhusa and the Sarson in Tables II and IV it is noticed that in all cases—with one or two exceptions—the figures for the Sarson are fairly high, and much higher than the corresponding figures for the Bhusa, tending in general towards a lower direction in the case of those constituents such as fibre which are only present in small quantities. In every case the co-efficients of the various constituents of the 'combined feed' are positive and normal.

In the second sub-period from 14th-20th December, the figures show much the same results.

During the third sub-period the average amount of Bhusa eaten by the animals was from 8 to 11 lb. and the amount of green Sarson from 22 to 24 lb. The highest and lowest figures for the digestibility of the combined diet were 53·31 and 47·94 and for the Sarson alone 61·75 and 46·44 respectively.

No negative results were found.

A reference to the weight curve shows that the animals preserved their weights well throughout the period of 5 weeks during which the Bhusa and Sarson was fed.

Taking these periods on Bhusa and Sarson certain general observations may be made. Table III shows the data concerning digestible protein, starch equivalents and nutritive ratios, and we note that the average daily digestible protein is about 0·16 lb. or 0·45 per 100 lb. of food given, the digestibility of whose protein is on an average 32 per cent. Taking into consideration the fact that during this whole period the weights of the animals remained constant, we may perhaps assume that this diet represents a close approximation to a maintenance diet for the bullocks at rest. There are certain facts brought out when we refer to the table showing the nitrogen balance of the animals on this diet. The total nitrogen given in the food has been computed and also the total nitrogen excreted in the urine and in the dung, and the balance throughout these periods is slightly on the negative side, indicating that this diet is just under what may be considered a maintenance ration. Armsby[1] gives the digestible protein required per day for a bullock weighing a thousand pounds as 0·5 lb. for American animals, which is considerably higher than the figure obtained in these trials.

If we bear in mind that the total period of Bhusa and Sarson was only 5 weeks, and also consider the fact that the 'nitrogen balance' during this period was negative, it would appear that the minimum daily protein requirement must be higher than the average figure of 0·15 lb. which was what the animals obtained in these trials.

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[1] Armsby, H. P. The nutrition of farm animals.

Reference to the weight curve during this period shows that the weight has been more or less maintained and on this alone one might conclude that the animal were receiving a maintenance ration, but if it be maintained that the nitrogen balance should be zero, then they certainly did not, and further trials will be necessary to determine what is the daily maintenance requirement in true digestible protein for Indian cattle, but in any case this is a remarkably low figure.

Second experimental period (Tables IV and V).

The diet was Bhusa alone and the period was from 23rd January to 4th February 1924.

The amount of Bhusa eaten per day by the animals during this period varies from 8 to 12 lb.; the highest and lowest figures for the digestibility of the Bhusa were 50 and 48. The percentage of crude protein in the Bhusa was low, being only 1·67, and this is reflected in the digestibility co-efficients of the same as found, which were negative for all the animals and consequently the figure for the daily digestible protein required is negative, an obviously absurd result indicating that the Bhusa does not constitute a maintenance ration even when the animals are fed as much as they can eat.

This is further shown in the weight curves from which it is seen that all the animals lost in weight consistently, and by referring to the nitrogen balance in Table V we notice a considerabe negative balance in all cases, clearly indicating that the animals are drawing on their reserves of body protein for maintenance.

It does not follow that Bhusa will always fail to maintain an animal at rest, this largely depends on the richness or otherwise of the material. In a previous publication[1] it was shown that when Bhusa contains only 1·72 per cent. of protein negative digestibilities were obtained, but positive figures were obtained when the Bhusa was twice as rich in protein.

It may be pointed out here that Bhusa was analysed from time to time throughout the period of the trials, and but slight differences in composition were found. The Bhusa figures, on which we have calculated the digestibility co-efficient of the Bhusa, are not exactly the same in the other periods, but this digestibility co-efficient of the Bhusa has been used later on in determining the digestibility co-efficient of other feeds. As, however, the difference is very small, no particular account has been taken of it.

Third experimental period (Tables VI and VII).

The diet employed was Bhusa, as in the preceding period, together with silced Shisham leaves, and was continued from 18th to 29th February 1924.

The average amount of Bhusa eaten per day by the animals was about 8 lb. and Shisham 24 lb. during the period, with the exception of one bullock which ate

[1] Lander, P. E., and Dharmani, Pandit Lal Chand. Some Digestibility Trials on Indian Feeding Stuffs. *Mem. Dept. of Agric. India, Chem. Ser.*, Vol. VII, No. 4.

14 lb. Shisham. The highest and lowest digestibility co-efficients of the combined diet were 45 and 36, respectively, and for the Shisham as such 39 and 28, respectively (Table VIII). Only in one case, for the ash, was a negative figure found. The highest digestibility co-efficient found for the protein of the combined diet was 47, and reference to Table VII shows that the daily protein digested averages just over 0·5 lb. except in the case of one animal where it was only 0·26, probably on account of the fact that it only ate a small quantity of the Shisham.

It is interesting to compare the very high figure for the daily protein digested on this diet, with the corresponding figure for the preceding diets. The Shisham is comparatively rich in protein which is apparently easily digested, although, taking into consideration the fact that the animals were fed as much Shisham as they cared to eat, and also the fact as revealed by Table VII that the nitrogen balance is on the negative side, it would not appear that the animal is fully able to utilize in the tissues all the protein which has actually been digested. This is an important factor to be kept in sight in computing the efficacy of any particular diet, even digested protein may not be entirely available for the general use of the animal because, as in this case, although the food was fed '*ad lib*' the nitrogen balance is still on the wrong side.

Turning to the weight curve we notice that the animals put on weight to a certain degree, but they do not quite recover to their initial figure.

We may compare the siloed Shisham with the fresh material such as was fed to the animals as recorded in the previous trials,[1] when only about 6 lb. daily could be taken. There is no doubt that the animals ate the material with relish and while it must be recognised that this material can only be regarded as a reserve in time of famine, when the main consideration is to keep an animal alive, its deficiencies must be sought for, not in its unpalatability, or in the figures as revealed by chemical analysis, but rather in the deficient availability of the digestion products in the tissues of the animal. How far these would be made more useful on prolonged feeding when the animal had become more accustomed to it, it is difficult to say.

Fourth experimental period (Tables VIII and IX).

Here siloed Shisham leaves alone were fed from 8th to 17th March 1924.

It was thought advisable to see how the animals would thrive when fed on nothing but Shisham. The average amount eaten per day by the animals during the period was 25 lb. the highest digestibility co-efficient being 39, about the same as in the previous period. The total protein digested per day is still in the region of 0·5 lb., but the negative nitrogen balance has very considerably increased. The explanation of this would appear to be that although considerable quantities of protein are daily digested, certain essential 'elements' are lacking which are

[1] Lander, P. E., and Dharmani, Pandit Lal Chand. Some Digestibility Trials on Indian Feeding Stuffs. *Mem. Dept. Agric. India, Chem.* Ser., Vol. VII, No. 4.

required by the animal, and in its effort to secure these it has recourse to the breaking down of its own tissues. This is in conformity with the well-known fact that an animal, fed on a diet deficient in certain mineral constituents will break down its tissues and die sooner than one which is being actually starved, owing to the excess work involved in the processes of digestion, the products of which cannot be utilized owing to general derangement which ensues. The possibility of the defect being due to some mineral deficiency rather than some defect of the proteins suggested itself and it was decided to carefully analyse the Shisham for its mineral content, and to compare the ash with that obtained from green Sarson. The results are given in Table X, from which we note that potassium, sodium, and phosphates are present in smaller quantities than in green Sarson and when fed on a pure Shisham ration the animal is only getting about one-third as much calcium in its daily ration as it would on a normal diet, although it is open to question whether during the period over which the observations were made this could be the cause of the defect in the diet. Work is being undertaken on the proteins of the Shisham, a direction in which it is perhaps more likely to find some explanation of the unsatisfactory nature of Shisham as a fodder for sustained replacement of ordinary green fodder.

It is clear that in these trials, neither the Shisham alone nor the Bhusa alone are sufficient maintenance rations, but a combination of the two effects some improvement.

During this period of Shisham alone all the animals decreased considerably in weight as shown by the curve, which decrease, coupled with the high negative nitrogen balance confirms the inadequacy of this material as a sole dietary. The animals lost 'condition.' They licked earth from the walls and mangers and tried to eat the wooden partitions. Their eyes became lacrymose and they showed reluctance to rise when sitting, and the urines showed a considerable deposit of broken cellular material; this may have been due either to the mineral content being deficient or to protein deficiency as already mentioned.

Fifth experimental period.

After the period of Shisham feeding alone it was decided to put the animals on an ordinary Farm ration for about a week in order to note any improvement in condition and this was continued from 27th March to 3rd April 1924 during which time the urines were collected as usual in order to see what changes, if any, occurred in the constituents of the urines, and for comparison, urines from four bullocks on an ordinary farm diet which had no been subjected to the experimental trials, were collected from 8th to 10th April 1924 and analysed. The figures from these urines are commented on later, along with the urines collected in the previous periods.

Some emphasis has been laid on the variations of weight noted during the various periods, and these have been attributed to the effects of the rations employed, particularly in the case of the Bhusa and Shisham diets. The variations in weight

on the pure Shisham diet, taken in conjunction with the fact that the nitrogen balance is unfavourable, has, in particular, been taken to indicate that this diet has produced an effect on the weight of the animal, but where the variations in weight are not very pronounced we must guard against attributing the effect noted solely to the diet and overlooking the possibility that the changes in live weight noted may be explained and accounted for by the amount of dry matter consumed and the average amount of material lying in the alimentary canal.

From the data given the following figures are found :—

Ration	Average weight in lb. of dry matter consumed per head per day
Bhusa-Sarson	11·91
Bhusa alone	8·65
Bhusa silage	12·39
Shisham silage	6·35

The difference in the stomach contents taken on an average during the four periods goes far to explain the changes in live weight which cannot be entirely attributed to the quality of food eaten. It would appear that the nitrogen balance is of greater value in adjudicating between the rations than slight variations in live weight as found on the balance, which variations may be due to other causes, and should be interpreted with caution.

Some observations on the urines of the animals.

In a maintenance ration there should be a fairly accurate balance between the total nitrogen in the food and that contained in the urine and dung. That part of the nitrogen found in the dung, if we exclude that derived from the secretions and other refuse derived from the digestive tract, is derived from the undigested portion of the food. This may be termed the exogenous nitrogen excretion. That part which is contained in the urine, however, is of an endogenous nature and is derived from various sources ; part coming from the amino acids which are taken from the digestive tract and de-aminised in the tissues, and part is derived from actual breakdown of tissue substance itself, which part is the endogenous nitrogen proper.

On a properly balanced ration the body ought not to have recourse to any pronounced utilization of its own tissues, especially when at rest and there should be an equal quantity, or less, nitrogen excreted in the urine and dung than that contained in the food. If it is found that the body is excreting more nitrogen than it is receiving the only conclusion that may be drawn is that for various reasons the food is not supplying all the material, either in quantity or quality that the body requires and the balance has to be made up from the only other available source, *viz.*, the tissues themselves. This fact is independent of the gross nutritive content of the diet as may be clearly perceived if we consider the complex nature of the general metabolic processes always taking place. The body is a very complicated machine

in which not only the broad basal facts of digestion of the proteins, fats and carbohydrates is to be considered, but also a large number of other co-ordinating factors, only a few of which are at present probably known. We have the illusive substances known as hormones to be considered, the secretions of the ductless glands, and undoubtedly a large number of other substances, all ultimately derived from the food and absolutely dependent upon the presence in the food of those molecular 'groupings,' which when introduced into the body will enable it to produce those substances, often only present in extremely small quantities, but which are so necessary for the proper co-ordination of the various bodily functions. If, therefore, the food is deficient in any of the directions indicated, it will not suffice either for maintenance or to keep the animal in health. It was, therefore, considered expedient not only to balance the total nitrogen intake against the output, but also to investigate to some degree the nature and quantity of the various nitrogenous constituents of the urine, a progressive increase in which would give some indication of internal tissue breakdown. Comment has already been made on the negative nitrogen balances as obtained on some of the diets.

While it is not easy to interpret the data which was obtained, certain factors nevertheless stand out :—Following the Bhusa and Sarson diets in which the daily figures showed a fair degree of uniformity without any very pronounced divergencies, we find that when the animals were transferred to a pure Bhusa diet the reaction of the urine altered considerably, an alkaline urine being replaced in many cases by an acid one. The figures for urea were low, as might be expected, while the ammonia and amino acids, creatinine and uric acid did not show any wide divergencies. On the Bhusa and Shisham diet the reaction of the urine again became alkaline. The ammonia and amino acids tended to rise, as also did the urea, whilst the uric acid and creatinine did not show any pronounced variations.

During the 'Shisham alone' period we noted that the urea figure rose considerably, this is the period when the most pronounced difference was noted between the total nitrogen intake and output, the animal obviously losing nitrogen but considerable difficulty is experienced in saying precisely in what form this excess of nitrogen exists. The figures for total nitrogen as determined by the Kjehldal method were very considerably higher than in any of the other periods. Difference of season may exert some effect on the various nitrogen figures for the urines as we progress from the cold winter months to the warmer weather of March. It is hoped that further work in the future will throw more light on these complicated factors and owing to the indecisive nature of the figures obtained it is not thought advisable to present the daily data in detail, but to give as an illustration the data from one animal only during the various experimental periods (Tables XI to XVII). The animal selected is No. III, the data from which is representative of those found from all the animals.

All the various ingredients were not determined throughout, because the range of investigation developed as the trials progressed.

The following points, however, are specially worthy of note :—

1. The alkalanity tends to diminish towards the end of the green Sarson-Bhusa period, decreasing still further on the Bhusa diet when an acid condition often prevailed. It increased, however, on the succeeding diet of Bhusa and Shisham to a much higher figure than the normal and maintained the high figure also on the pure Shisham diet, the figure dropping somewhat towards the end of the final normal diet.
2. The ammonia and amino acid figures increase to a very high degree on the Shisham alone diet, a period when the alkalinity is at its maximum, and also show some increase on the Bhusa-Shisham diet, but the creatinine figures although showing an upward tendency at this time do not increase in the same proportion, a point on which comment will be made later.
3. The urea figures are low on all the diets except the pure Shisham and ordinary farm diets, the latter being due perhaps to effects carried over from the former. The urea figures for the Shisham diet are extraordinarily high.
4. The uric acid figures do not show any very great fluctuations and are in all cases lower than those obtained from the animals when on the ordinary farm diet. It is possible that the effect of the preceding diets does not show itself immediately in the case of uric acid, but the figures are not of sufficient variation to justify conclusions being drawn.
5. The creatinine figures show some decided increase when the animals are put on the Bhusa and Shisham diets, and as creatinine is generally recognized as being indicative of endogenous metabolism we have to try and correlate the increase of creatinine with corresponding increase of alkalinity, on the one hand, and the ammonia and amino acids on the other.

It would appear that the increases in these directions may be explained by assuming that as the diets were deficient in the particular protein 'groupings' which the animal requires for its general metabolism, a call is made on the muscle proteins with consequent breakdown thereof and increases output of the end products of katabolism.

McCollum[1] (*Jour. of Biol. Chem.*, Vol. XVI, 1913, p. 299) has pointed out that the group of metabolic end products of nitrogenous nature present in the urine of an animal whose diet contains no nitrogen shows relationships which are not found in urines under any other condition, and we are here dealing with diets whose nitrogen constituents are abnormal with corresponding abnormal relationships in

[1] McCollum and Hoagland. Studies of the endogenous metabolism of the pig as modified by various factors. *Jour. of Biol. Chem.*, Vol. XVI, p. 299, 1913.

the urine. He further points out that the most conspicuous and least variable known constituents of the group of endogenous end products of metabolism, is creatinine, and Mendel and Rose[1] (*Jour. of Biol. Chem.*, Vol. X, p. 247, 1911), studying the conditions under which creatinine is eliminated have shown conclusively that in fasting rabbits and dogs when the tissues are being starved there is always an increase in the output of total creatinine.

It would appear that whenever an animal is put under such conditions that the endogenous type of metabolism is increased, a rise of creatinine is found.

In endeavouring to seek an explanation of the increased alkalinity it may be pointed out that it has been found that the water extract of 100 grm. of the fresh shisham leaves required 70 c.c. of normal alkali to neutralise the non-volatile acids compared with about 20 in the case of green oats, and 16-17 with *Juar*. The non-volatile acids do not increase in the case of Shisham during ensilage, but rise very much in the case of other green fodders. Further, the ammonia and amino acids in a similar extract of the fresh leaves have been found to be equivalent to 20-30 c.c. of normal acid against only 4-7 for green oats and 0·4-0·5 in the case of *Juar*.

The actual extract of the leaves themselves is neutral to ordinary indicators and therefore the acids must be in a combined condition. Now McCollum[2] has found (*Jour. of Biol. Chem.*, Vol. XVI, 1913, p. 302) whilst investigating the effect of acid and basic salts and of free mineral acids on the endogenous nitrogenous metabolism that when the diet is acid, ammonia is liberated in quantities sufficient to neutralise the acid present in the diet and that this ammonia nitrogen is to a considerable extent derived from additional protein destruction in excess of that which would take place if these acids were not present.

Bearing in mind that the protein of the Shisham leaves is of an abnormal character, and that the feed is very rich in non-volatile acids it would appear that a reasonable explanation of the high alkalinity is to be found in an effort of the body to counteract the acidity; furthermore the body being unable fully to utilize the proteins of the Shisham, they are dealt with possibly by the liver and the very high urea figure is the result, the lesser rise in the creatinine being explained by the increased endogenous nitrogen metabolism called forth as a result of the demands of the body when a diet deficient in the requisite nitrogenous constituents, or in a form in which the body cannot fully utilize them, is fed.

The sulphur figures are interesting. It will be noticed that the highest figures were obtained on the green Sarson and Bhusa period in the first half of January, becoming much lower in the latter part of the month on the Bhusa diet, and in February on the Bhusa and Shisham, dropping still lower in March on the pure Shisham diet ending on the 17th. After this the animals were put on the ordinary

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[1] Mendel and Rose. Creatine and Creatinine Metabolism. *Jour. of Biol. Chem.*, Vol. X, 1911, p. 247.

[2] McCollum and Hoagland. Studies of the endogenous metabolism of the pig as modified by various factors. *Jour. of Biol. Chem.*, Vol. XVI, 1913, p. 302.

farm diet and the observations continued from the 27th March upto the 3rd April when it will be seen that the figures again rise considerably.

In conclusion, it may be mentioned that only a few isolated analyses were done on the hippuric acid.

Summary.

1st Period. Sarson and Bhusa. The effect of adding Sarson to Bhusa was to diminish considerably the degrees of negativity in the co-efficient found in the Bhusa period.

The co-efficients for the protein and ash in the Bhusa period were negative, but the co-efficients of the combined feed were positive and normal.

The animals preserved their weights.

A slight negative nitrogen balance indicates that the ration was just under a maintenance ration.

2nd Period. Bhusa Alone. The digestibility co-efficients for the protein are negative.

The nitrogen balance is negative and the ration is not a maintenance ration.

3rd Period. Shisham Silage and Bhusa. All the digestibility co-efficients are positive except in the case of ash. The protein co-efficient is positive, but the nitrogen balance is negative, indicating the inability of the animal to fully utilize the protein. No actual loss in weight occurred.

4th Period. Shisham Silage alone. The digestibility co-efficient of the protein is positive but the nitrogen balance showed a considerable increase on the negative side, a result probably explained by the protein inefficiency of the Shisham silage.

The ash content of the Shisham cannot fully explain its inadequacy as a ration.

Neither Shisham silage nor Bhusa alone is a maintenance ration—but a combination of the two effects some improvement.

The weights of the animals during this period showed a considerable decline.

Some observations on the urines are given, the outstanding features being the pronounced difference between the total nitrogen intake and output when the animals were fed Shisham silage alone.

In conclusion, the authors wish to express their thanks to Mr. Stewart, Professor of Agriculture for assistance in providing the bullocks, fodders, etc., and to Dr. Ramji Narain, S. Sher Singh, S. Kishan Singh and S. Balwant Singh of the Chemical Laboratory for assistance in analyses.

TABLE I.

Composition of feeds during the different periods.

Feed	Periods	Moisture	Dry matter	Ash	Fat	Crude fibre	Protein	Nitrogen free extract
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Sarson .	6—13th Dec. 1923 (8 days).	84·64	15·36	2·17	0·45	4·53	1·36	6·85
Do. .	14—20th Dec., 1923 (7 days).	87·03	12·97	2·43	0·36	2·55	1·41	6·22
Do. .	4—13th Jan. 1924 (10 days).	83·73	16·27	2·27	0·45	4·96	1·09	7·50
Bhusa .	6—20th Dec. 1923 (15 days).	10·98	89·02	11·07	0·43	39·95	1·73	35·85
Do. .	4—13th Jan. 1924 (10 days).	12·83	87·17	9·63	0·46	40·32	2·01	34·75
Do. .	23rd Jan. to 4th Feb. 1924 (13 days).	9·86	90·14	8·83	0·40	40·80	1·67	38·44
Do. .	18—29th Feb. 1924 (12 days).	9·44	90·56	9·75	0·44	40·43	1·91	38·03
Shisham Silage.	Do. .	72·10	27·90	5·09	0·85	8·22	4·51	9·43
Do. .	8—17th Mar. 1924 (10 days).	75·43	24·57	4·48	0·88	7·39	3·45	8·38

Sarson. It is an oil seed crop and is usually fed to cattle when young before the formation of seed. It is considered to be a good green fodder in winter. The green Sarson was analysed daily and the figures given are the averages of daily analyses done during a period.

Shisham silage. Leaves of ' Dalbergia Sissoo ' were gathered in the last week of June 1923 for siloing and were fed to the bullocks from 5-II-24—17-III-24. The figures given are also the averages of the daily analyses.

Wheat bhusa. Bhusa was analysed thrice during a period. The figures given for different periods are the averages of these estimations.

TABLE II.

Bhusa and Sarson.

Period	No. of bullock	Feed consumed per day in lb.			Digestibility co-efficient of combined feed Bhusa and Sarson.						Computed digestibility co-efficient of Sarson.					
		Bhusa	Green fodder	Total dry matter	Dry matter	Ash	Fat	Crude fibre	Protein	Nitrogen free extract	Dry matter	Ash	Fat	Crude fibre	Protein	Nitrogen free extract
6—13th December 1923 (8 days). Green Sarson and Bhusa.	1	7·96	23·80	10·75	51·73	12·59	59·50	60·50	29·62	55·35	59·99	80·62	65·52	52·60	61·44	64·76
	2	11·05	23·97	13·52	49·13	15·05	58·86	60·05	19·20	47·55	47·05	72·34	72·28	34·90	50·59	51·15
	3	8·52	23·70	11·22	55·68	32·00	62·84	63·30	33·07	57·06	70·74	—14·42	74·38	53·48	61·77	68·58
	4	11·56	23·83	13·95	48·54	16·54	60·57	61·40	15·21	43·80	46·10	100·00	72·76	43·86	49·80	21·60
Average for the period	..	..	..	..	51·27	19·05	60·44	61·31	24·28	50·94	55·97	59·64	71·24	46·21	55·90	51·52
14—20th December 1923 (7 days). Green Sarson and Bhusa.	1	8·97	23·89	11·08	48·74	20·29	57·75	57·01	36·91	52·05	51·98	82·50	60·38	20·70	74·28	56·54
	2	11·18	24·00	13·07	50·37	26·89	62·08	59·71	31·74	51·89	54·44	95·18	80·68	10·72	69·10	53·50
	3	8·66	23·77	10·80	46·73	18·73	59·88	54·26	35·47	50·05	42·71	100·80	72·56	—15·30	64·53	48·12
	4	11·72	24·00	13·55	45·45	13·46	58·00	55·79	24·84	48·06	30·87	81·60	71·60	—21·68	64·12	35·50
Average for the period	..	..	..	..	47·82	19·84	59·43	56·69	32·24	50·51	45·00	90·02	72·81	15·71	68·01	48·42
4—13th January 1924 (10 days). Green Sarson and Bhusa.	1	7·39	24·00	10·35	48·90	6·70	65·16	57·82	31·45	54·50	51·16	36·57	73·69	44·48	74·52	60·43
	2	8·39	23·61	11·15	48·73	4·47	62·68	58·13	24·52	54·01	46·44	36·30	75·12	34·05	58·55	58·52
	3	7·63	22·20	10·26	47·94	7·26	63·17	59·18	27·76	49·88	47·15	62·70	74·74	38·62	64·37	49·01
	4	10·63	24·00	13·17	53·31	18·12	66·76	60·54	32·28	57·96	61·80	84·58	81·34	42·61	89·96	69·04
Average for the period	..	..	..	..	49·72	9·14	64·44	58·92	29·00	54·09	51·64	55·04	76·22	39·94	71·85	59·25
Averages for 3 periods	..	..	..	..	49·60	16·01	61·44	58·97	28·51	51·85	50·87	68·23	73·42	33·99	65·25	53·06

Table III.

Bhusa and Sarson—contd.

Period	No. of bullock	Feed consumed per day in lb. Bhusa	Green Fodder	Total dry matter	Starch equivalents per day	Protein digested per day in lb.	Nutritive ratio 1 :	Mean daily nitrogen balance in grm.
			Sarson					
6—13th December 1923 (8 days). Green-Sarson and Bhusa.	1	7·96	23·80	10·75	3·17	0·14	38·2	— 9·4
	2	11·05	23·97	13·52	3·54	0·10	63·8	— 13·2
	3	8·52	23·70	11·22	3·51	0·16	35·9	— 11·6
	4	11·56	23·83	13·95	3·25	0·08	79·3	— 24·7
14—20th December 1923 (7 days). Green-Sarson and Bhusa.	1	8·97	23·89	11·08	2·92	0·18	27·6	— 5·1
	2	11·18	24·00	13·07	3·47	0·17	36·6	— 5·1
	3	8·66	23·77	10·80	4·08	0·17	27·2	— 4·4
	4	11·72	24·00	13·55	3·11	0·14	43·8	— 9·4
4—13th January 1924 (10 days). Green-Sarson and Bhusa.	1	7·39	24·00	10·35	2·98	0·13	38·5	— 4·4
	2	8·39	23·61	11·15	3·12	0·11	49·4	— 6·5
	3	7·63	22·20	10·26	2·77	0·11	43·8	— 4·4
	4	10·63	24·00	13·17	3·99	0·15	44·0	— 5·1

Table IV.

Digestibility co-efficients of Bhusa.

Period	No. of bullock	Dry matter	Ash	Fat	Crude fibre	Protein	Nitrogen free extract
23rd January to 4th February 1924 (13 days). Bhusa alone.	1	47·48	—16·17	38·05	63·17	—44·75	49·98
	2	49·90	—16·17	28·37	66·44	—27·90	51·26
	3	48·34	—30·74	29·40	66·52	—30·00	50·95
	4	49·75	—17·22	34·30	65·50	—40·86	52·53

Table V.

Bhusa—contd.

Period	No. of bullock	Feed consumed per day in lb. Bhusa	Green fodder	Total dry matter	Starch equivalents per day	Protein digested per day in lb.	Nutritive ratio 1 :	Mean daily nitrogen balance in grm.
23rd January to 4th February 1924 (13 days). Bhusa alone.	1	7·97	..	7·18	1·67	—0·06	..	— 21·1
	2	9·92	..	8·94	2·28	—0·05	..	— 17·4
	3	8·63	..	7·78	1·97	—0·04	..	— 14·5
	4	11·84	..	10·70	2·71	—0·08	..	— 21·8

TABLE VI.

Digestibility co-efficients of Bhusa and Shisham silage.

Period	No. of bullock	Dry matter	Ash	Fat	Crude fibre	Protein	Nitrogen free extract
18—29th February 1924 (12 days). Bhusa and Shisham silage.	1	45·10	20·77	38·25	51·02	47·48	49·20
	2	36·13	—5·04	29·08	47·18	32·70	38·24
	3	44·60	25·96	33·81	52·00	44·55	51·45
	4	45·30	15·65	39·39	53·60	44·46	48·58

TABLE VII.

Bhusa and Shisham silage—contd.

Period	No. of bullock	FEED CONSUMED PER DAY IN LB.			Starch equivalent per day	Protein digested per day in lb.	Nutritive ratio 1 :	Mean daily nitrogen balance in grm.
		Bhusa	Green fodder	Total dry matter				
			Shisham silage					
18—29th February 1924 (12 days). Bhusa and Shisham silage.	1	6·26	24·00	12·36	3·13	0·57	8·4	—8·0
	2	7·33	14·02	10·57	1·71	0·26	14·1	—10·9
	3	5·50	23·94	11·66	2·56	0·49	9·4	—12·3
	4	9·11	24·00	14·95	3·78	0·56	10·8	—5·8

TABLE VIII.

Digestibility co-efficients of Shisham silage.

Period	No. of bullock	Dry matter	Ash	Fat	Crude fibre	Protein	Nitrogen free extarct
8—17th March 1924 (10 days). Shisham silage alone.	1	38·83	13·05	31·23	37·43	53·54	48·71
	2	28·20	—19·40	25·30	27·09	47·17	46·78
	3	38·88	5·55	29·20	36·37	52·55	54·39
	4	38·99	15·50	26·53	35·10	53·90	50·26

TABLE IX.

Shisham silage—contd.

Period.	No. of bullock	FEED CONSUMED PER DAY IN LB.			Starch equivalents per day	Protein digested per day in lb.	Nutritive ratio 1:	Mean daily Nitrogen balance in grm.
		Bhusa	Green fodder	Total dry matter				
			Shisham silage					
8th to 17th March 1924 (10 days). Shisham silage alone.	1	..	27·06	6·55	1·75	0·50	4·1	—44·3
	2	..	22·44	5·52	1·17	0·36	3·9	—37·0
	3	..	27·76	6·82	1·89	0·50	4·3	—28·3
	4	..	26·50	6·51	1·69	0·49	3·9	—39·9

TABLE X.

Composition of the ashes of Sarson and Shisham silage.

	Percentage in Ash							
	In sol; in dil; HCl.	Fe_2O_3 Al_2O_3	CaO	MgO	Na_2O	K_2O	So_3	P_2O_5
Sarson . . .	32·59	2·50	18·50	4·22	3·91	14·70	2·41	4·16
Shisham silage . .	20·41	4·13	30·20	5·72	0·99	9·60	1·41	2·28

Daily ash intake in Sarson and Shisham silage.

Feed	Feed eaten per day in lb.	Ash per cent. on feed	Quantities eaten per day in grm.							
			In sol; in dil; Hcl.	Fe_2O_3 Al_2O_3	CaO	MgO	Na_2O	K_2O	So_3	P_2O_5
Green Sarson . .	23·45	2·27	78·70	6·04	44·67	10·20	9·44	35·50	5·82	10·05
Shisham silage .	23·98	4·48	99·50	20·13	14·72	27·89	4·83	46·80	6·87	11·12

TABLE XI.

Analysis of the urines. Feed: Sarson green and Bhusa. Animal III. Period: 6th December 1923 to 13th December 1923.

Analytical composition in terms of grm. of nitrogen.

Date	Volume in C. C.	Density at 60°F.	Alkalinity, C. C. N/10 acid for 100 c.c. urine	Ammonia and amino acid	Urea	Creatinine	Sum of different constituents	Total (Kjeldahl's method)
6th December 1923	3014	1037	16·80	0·54	13·40	0·95	14·89	16·10
7th ,, ,, ...	3237	1038	28·80	0·71	18·50	1·15	20·36	25·40
8th ,, ,, ...	3643	1044	54·40	2·71	23·00	1·96	27·67	33·10
9th ,, ,, ...	4282	1046	22·80	1·97	20·90	3·67	26·54	28·30
10th ,, ,, ...	3423	1046	18·00	1·85	13·30	3·43	18·58	24·40
11th ,, ,,	3500	1045	26·00	1·19	7·84	2·56	11·59	18·40
12th ,, ,,	3680	1045	12·80	0·81	5·74	3·29	9·84	17·20
13th ,, ,, ...	4020	1045	20·40	0·84	5·55	2·88	9·27	18·30

Table XII.

Analysis of the urines. Feed: Sarson green and Bhusa. Animal III. Period: 14th December 1923 to 20th December 1923.

Analytical composition in terms of grm. of nitrogen.

Date	Volume in C. C.	Density at 60 F.	Alkalinity C. C. N/10 acid for 100 c.c. urine	Ammonia and amino acid	Urea	Creatinine	Sum of different constituents	Total (Kjeldahl's method)
14th December 1923	4040	1045	25·20	0·65	5·65	2·04	8·34	17·90
15th ,, ,, ...	3730	1045	14·00	0·84	7·43	3·39	11·66	18·20
16th ,, ,, ...	4680	1042	18·00	1·11	9·36	4·01	14·48	20·50
17th ,, ,, ...	4200	1044	13·20	1·03	9·16	2·15	12·34	19·50
18th ,, ,, ...	4440	1043	17·60	1·24	9·06	3·93	14·23	14·60
19th ,, ,, ...	4020	1044	14·40	0·88	6·31	3·10	10·29	..
20th ,, ,, ...	3820	1045	13·20	1·05	7·03	2·66	10·74	11·20

Table XIII.

Analysis of the urines. Feed: Green Sarson and Bhusa. Animal III. Period: 5th to 14th January 1924.

Analytical composition in terms of grm. of nitrogen.

Date	Volume in c. c.	Density at 60° F.	Alkalinity, c. c. N-10 acid for 100 c. c. urine.	Ammonia and amino acid	Urea	Uric acid	Creatinine	Sum of different constituents	Total (Kjeldahl's method)	Sulphates as SO_3		
										Total	Inorganic	Ethereal
5th January 1924 . .	3600	1039	13·20	0·38	2·46	0·46	3·01	6·31	12·60	23·12	19·66	3·46
6th ,, ,, . .	3960	1039	12·40	0·58	2·82	0·39	3·60	7·39	13·74	22·57	21·62	0·95
7th ,, ,, . .	3940	1038	8·80	0·64	2·79	0·56	1·43	5·42	13·24	23·76	18·95	4·81
8th ,, ,, . .	4260	1030	9·20	0·88	2·59	0·50	2·53	6·50	12·39	19·80	15·89	3·91
9th ,, ,, . .	3460	1037	13·60	0·68	2·95	0·46	2·42	6·51	11·73	19·41	15·64	3·77
10th ,, ,, . .	3850	1039	11·60	0·75	3·46	0·63	3·30	8·14	12·90	22·91	17·98	4·93
11th ,, ,, . .	4020	1038	13·60	0·85	3·90	0·56	3·36	8·67	13·75	21·39	16·08	5·31
12th ,, ,, . .	5840	1031	2·40	1·34	4·52	0·54	4·29	10·69	14·25	21·96	16·65	5·31
13th ,, ,, . .	4020	1040	6·80	1·90	3·82	0·59	2·33	8·64	12·26	23·04	18·41	4·63
14th ,, ,, . .	4750	1033	6·00	1·40	3·71	0·64	3·24	8·99	9·17	18·91	14·06	4·85

Table XIV.

Analysis of the urines. Feed: Bhusa. Animal III. Period: 23rd January 1924 to 4th February 1924.

Analytical composition in terms of grm. of nitrogen.

Date	Volume in c. c.	Density at 60° F.	Alkalinity, c. c. N-10 acid for 100 c. c. urine.	Ammonia and amino acid	Urea	Uric acid	Creatinine	Sum of different constituents	Total (Kjeldahl's method)	Sulphates as SO_3 Total	Sulphates as SO_3 Inorganic	Sulphates as SO_3 Ethe real
23rd January 1924	2575	1038	18·00	0·41	1·40	0·22	2·35	4·38	10·30	7·01	4·28	2·73
24th " "	2500	1037	12·40	0·46	2·01	0·33	1·68	4·48	10·30	7·45	3·98	3·47
25th " "	4050	1031	3·60	0·53	2·08	0·39	4·17	7·17	12·03	8·18	5·55	2·63
26th " "	4300	1038	4·80	0·72	2·72	0·49	3·69	7·62	12·30	11·61	5·20	6·41
27th " "	3500	1033	3·20	0·81	2·15	0·32	3·25	6·53	11·00	7·21	4·27	2·94
28th " "	3760	1032	1·40	1·09	2·67	0·42	2·57	6·75	11·28	6·47	3·16	3·31
29th " "	3665	1033	3·20	0·83	2·49	0·37	3·77	7·46	8·14	6·38	2·86	3·52
30th " "	3400	1033	3·60	1·01	2·89	0·29	3·07	7·26	11·90	5·92	2·18	3·74
31st " "	2900	1032	6·40	1·20	2·57	0·35	2·91	7·03	10·79	4·87	1·74	3·13
1st February 1924	3025	1032	2·60	1·33	3·57	0·38	3·30	8·58	11·53	5·93	2·48	3·45
2nd " "	2860	1034	3·60	1·84	4·32	0·38	3·23	9·77	11·84	4·86	3·55	1·31
3rd " "	3120	1034	2·40*	2·06	4·40	0·43	3·24	10·13	12·23	7·36	3·81	3·55
4th " "	3350	1032	4·40	1·49	3·40	0·43	2·27	7·59	12·02	6·79	3·20	3·59

* Urine acidic c. c. N-10 alkali for 100 c. c. urine.

Table XV.

Analysis of the urines. Feed: Shisham silage and Bhusa. Animal III. Period: 19th February 1924 to 1st March 1924.

Analytical composition in terms of grm. of nitrogen.

Date	Volume in c. c.	Density at 60° F.	Alkalinity, c. c. N-10 acid for 100 c. c. urine	Ammonia and amino acid	Urea	Uric acid	Creatinine	Hippuric acid	Sum of different constituents	Total (Kjeldahl's method)	Sulphates as SO_3 Total	Sulphates as SO_3 Inorganic	Sulphates as SO_3 Ethereal
19th February 1924	6700	1036	32·00	3·51	..	0·64	2·79	..	..	50·26	8·38	4·29	4·09
20th " "	6340	1038	38·00	4·37	16·61	0·67	3·08	..	24·73	41·20	8·11	3·04	5·07
21st " "	5520	1041	46·80	5·21	21·30	0·57	2·37	..	29·45	46·20	6·62	1·77	4·85
22nd " "	5520	1042	66·00	7·14	..	0·52	3·09	..	..	46·65	6·62	1·33	5·29
23rd " "	4630	1046	47·60	6·53	19·17	0·60	3·09	5·79	35·18	47·46	6·11	0·93	5·18
24th " "	6560	1040	33·60	8·90	13·12	0·56	3·08	..	25·66	55·10	6·01	0·45	5·56
25th " "	5630	1038	40·80	8·84	23·76	0·56	2·01	..	36·17	50·28	6·08	0·45	5·63
26th " "	6540	1039	38·80	10·92	24·20	0·55	2·43	7·06	45·16	53·50	9·94	0·65	9·29
27th " "	6800	1037	21·80	9·25	23·12	0·67	3·03	..	36·07	49·85	5·44	0·68	4·76
28th " "	6520	1036	51·20	19·24	16·30	0·73	2·38	..	38·65	48·78	7·04	0·78	6·26
29th " "	6420	1035	47·20	7·83	22·02	0·64	1·66	..	32·15	43·66	2·83	0·51	2·32
1st March 1924	6160	1037	78·40	9·18	14·05	0·58	2·10	5·73	31·64	45·34	2·83	0·37	2·46

TABLE XVI.

Analysis of the urines. Feed: Shisham silage only. Animal III. Period: 8th to 17th March 1924.

Analytical composition in terms of grm. of nitrogen.

Date	Volume in c. c.	Density at 60° F.	Alkalinity, c. c. N-10 acid for 100 c. c. urine	Ammonia and amino acid	Urea	Uric acid	Creatinine	Hippuric acid	Sum of different constituents	Total (Kjeldahl's method)	Sulphates as SO_3 Total	Sulphates as SO_3 Inorganic	Sulphates as SO_3 Ethereal
8th March 1924 .	9200	1031	36·40	16·10	44·98	0·54	2·94	..	64·56	78·56	1·29	0·92	0·37
9th ,, ,, .	6200	1031	60·80	11·40	..	0·33	2·64	3·65	..	55·74	1·12	0·62	0·50
10th ,, ,, .	6200	1036	44·80	11·60	34·91	0·42	2·55	..	49·48	54·00	1·24	0·50	0·74
11th ,, ,, .	7620	1032	40·00	14·30	46·41	0·51	3·27	..	64·49*	58·67	1·52	0·91	0·61
12th ,, ,, .	8840	1029	46·00	18·20	44·20	0·41	2·91	7·13	72·85	84·17	1·92	1·77	0·15
13th ,, ,, .	9890	1027	21·20	13·60	53·00	0·34	3·24	..	70·18	81·68	1·97	1·18	0·79
14th ,, ,, .	8600	1026	28·80	15·80	43·87	0·47	5·07	..	65·21	72·94	1·77	1·21	0·56
15th ,, ,, .	5860	1027	68·40	15·50	23·09	0·22	1·87	..	40·68	50·52	0·70	0·70	..
16th ,, ,, .	6340	1026	51·60	16·70	30·01	0·11	1·85	..	48·67	54·85	0·88	0·63	0·25
17th ,, ,, .	5920	1031	44·60	10·40	19·19	0·12	2·22	3·51	35·44	55·17	0·71	0·47	0·24

* A discrepancy was found between the total nitrogen as found by the Kjeldahl's method and the addition of the individual nitrogen constituents.

TABLE XVII.

Analysis of the urines. Feed: Farm diet. Animal III. Period: 27th March 1924 to 3rd April 1924.

Analytical composition in terms of grm. of nitrogen.

Date	Volume in c. c.	Density at 60° F.	Alkalinity, c. c. N-10 acid for 100 c. c. urine.	Ammonia and amino acid.	Urea	Uric acid	Creatinine	Hippuric acid	Sum of different constituents.	Total (Kjeldahl's method)	Sulphates as SO_3 Total	Sulphates as SO_3 Inorganic	Sulphates as SO_3 Ethereal
27th March 1924 .	6080	1040	20·00	17·21	31·44	1·41	2·37	..	52·43	54·49	14·60	8·51	6·09
28th ,, ,, .	5950	1039	25·70	13·39	30·88	0·90	1·92	..	47·09	60·33	16·72	10·59	6·13
29th ,, ,, .	6860	1039	56·00	..	42·67	0·95	1·88	8·73	..	78·40	20·38	11·59	8·79
31st ,, ,, .	6200	1041	38·00	19·10	65·64	1·17	1·46	..	67·37	73·60	12·03	5·38	6·65
1st April 1924 .	5800	1042	33·00	21·70	45·16	1·50	1·68	..	70·04	70·82	10·79	1·97	8·82
2nd ,, ,, .	4200	1045	39·50	14·07	16·17	0·36	0·80	..	31·40	47·29	7·35	4·20	3·15
3rd ,, ,, .	4900	1040	40·00	16·80	30·20	0·50	1·13	5·46	54·09	57·24	11·61	5·73	5·88
8th ,, ,, .	6340	1035	16·25	15·53	47·75	0·62	0·99	..	64·89	79·20	8·62	5·39	3·23*
9th ,, ,, .	5240	1034	12·50	11·90	45·90	0·64	1·44	..	59·88	73·50	8·59	3·20	5·30*
10th ,, ,, .	5060	1033	18·70	10·42	39·83	0·38	0·72	4·97	56·32	62·24	7·74	4·20	3·54*

* Corresponding figures for an animal not subjected to experiments.

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THE EFFECT OF MANURING A CROP ON THE VEGETATIVE AND REPRODUCTIVE CAPACITY OF THE SEED.

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Introductory.

It is a matter of common knowledge that a crop is manured with a view to obtain increased yields and that manuring with cattle manure is preferable to any other form of manuring, especially to manuring with mineral manure alone.

It is, however, not generally known that manuring a crop and the nature of the manure have any influence on the resulting seed in regard to its capacity in the nutrition of its own seedling. The results of experiments described here throw light on this aspect of manuring.

They show :—

1. that a manured crop gives a seed with better cropping value than a crop that has not been manured,
2. that the seed from a crop manured with farm yard manure is superior to the seed obtained from a crop receiving mineral manure.

The investigation originated from an accidental observation by one of us (B.V.N.) in September 1921, while testing the malting capacities of different samples of *cholam* (*Andropogon Sorghum*) and *ragi* (*Eleusine coracana*). These samples had to be tested for their diastatic value, 72 hours after being spread out in moist sand in pots. But as accident would have it, they could not be seen for about a month, during which time, the laboratory boy was watering the young seedlings. The striking differences in the growth of two sets of plants, were traced to the fact that they came from the seed raised from cattle manure and no manure plots of the Permanent Manurials. This observation, however interesting, had to lie over for the time being.

Meanwhile, Lieut. Colonel R. McCarrison, I.M.S., in the course of his experimental determination of the nutritive and Vitamin values of rices in common use in India,[1] suspected that these values might possibly vary with soil conditions. At the suggestion of Dr. R. V. Norris, then Agricultural Chemist to the Madras Government, *ragi* grown on the Permanent Manurial Plots at the Central Farm, Coimbatore, was tested and it was found that the nutritive and Vitamin values of this grain varied with the manurial treatment of the soil.[2]

This finding gave a further stimulus to the investigation on plant nutrition.

The material used in these experiments was obtained from the Permanent Manurial Plots at the Agricultural College and Research Institute, Coimbatore. These plots were laid out in September 1909 by the then Agricultural Chemist, Dr. W. H. Harrison. A detailed account of these plots and the results of intensive cropping during 13 years is given by Dr. R. V. Norris[3].

The plots are ten in number. Seven of these receive artificial manures *i.e.*, nitrogen, phosphoric acid, and potash alone or in combination, while two plots have been treated with cattle manure and one is not manured at all. The general scheme of manuring is as below :—

Plot	Manure
1. (No)	No Manure
2. (N)	Nitrogen
3. (N+K)	Nitrogen *plus* potash
4. (N+P)	Nitrogen *plus* phosphate.
5. (N+K+P)	Nitrogen *plus* potash *plus* phosphate.
6. (K+P)	Potash *plus* phosphate.
7. (K)	Potash.
8. (P)	Phosphate.
9. (C. M.)	Cattle manure (continuous).
10. (C. M. R.)	Cattle manure (application stopped since 1916 and therefore residual).

The nature and amounts of manures in use have been :—

Ammonium sulphate	1 cwt. per acre for nitrogen.
Potassium sulphate	1 cwt. per acre for potash.
Super phosphate	3 cwt. per acre for phosphate.
Cattle manure (a mixture of dung, urine and litter)	5 tons per acre.

The plots have been under intensive cultivation from their inception with a view to emphasise the differential action of the manures. All crops are grown under irrigation and cultural operations are done by hand. 46 crops have been taken off the plots up to date. The crops usually grown are *ragi* (*Eleusine coracana*), *cholam*

[1] McCarrison, R. *Ind. Med. Res. Mem.* No. 2, 1924.
[2] McCarrison, R. *Brit. Med. Jour.* March 29, 1924.
[3] Norris R. V. Note on the Permanent Manurial Plots, Coimbatore. *Mem. Dept. Agri. India, Chem. Ser.*, Vol. VI, No. 8.

(*Andropogon Sorghum*), *pani varagu* (*Panicum miliaceum*), wheat (*Triticum vulgare*) and occasionally cotton and tobacco.

It was with the seed obtained from these differently manured plots, the experiments described below were carried out. To avoid lengthy description of the nature of the seed and the consequent confusion that may arise, the seeds from the different manurial plots are named after their respective plots. For example,

"No manure seed" means seed from a crop that has not been manured;

"Mineral manure seed" means seed from a crop manured with complete mineral manure, namely, N+K+P;

"Cattle manure seed" means seed from a crop manured with cattle manure.

I. Experiments with plants.

The cultural experiments were carried out in pots, small plots measuring four square feet in area and on the field.

The object of the experiments being the study of the effect of manuring a crop on the seed as judged by the crop raised from it, the seeds from the different Permanent Manurial Plots were sown in a soil of moderate fertility. It was not manured at least during the previous year. The analysis of the soil is given below:—

Analysis of the soil used in the cultural experiments.

	Per cent.
Nitrogen	0·039
Total phosphoric acid (P_2O_5)	0·071
Total potash (K_2O)	0·475
Phosphoric acid (P_2O_5) soluble in 1 per cent. citric acid	0·017
Potash (K_2O) soluble in 1 per cent. citric acid	0·063

In the case of pot and small plot culture experiments, the soil was prepared by passing it through a two mm. sieve and the portion that passed through the sieve was thoroughly mixed up and put into the pots. The packing of the soil in the pots was done with the utmost care to ensure, as far as possible, similar conditions of packing. Sowing was done liberally at first and when the seedlings were about a fortnight old they were thinned to the same number in all the pots. Watering was done as required and cultural operations were carried out with the utmost care. The experiments were replicated in every case. In the statement of results the total or average yields are recorded and where necessary individual results of replications are given.

At the end of the experiment the crop was harvested, dried in air or at 100°C till constant in weight and the final weights of the produce recorded.

Experiment I.

Pot cultures—17th Sep. to 16th Nov. 1923.—The first experiment was carried out with the seed from the ten differently manured plots, the seed used being *ragi* from crop No. 38 from the Permanent Manurial Plots. The seed was sown in plots on 17th Sep. 1923 and harvested on 16th Nov. 1923. The experiment was done in duplicate and the pots were thinned down to three plants in each. The heights of plants were measured periodically. The results are reproduced in Table I (Plate I.)

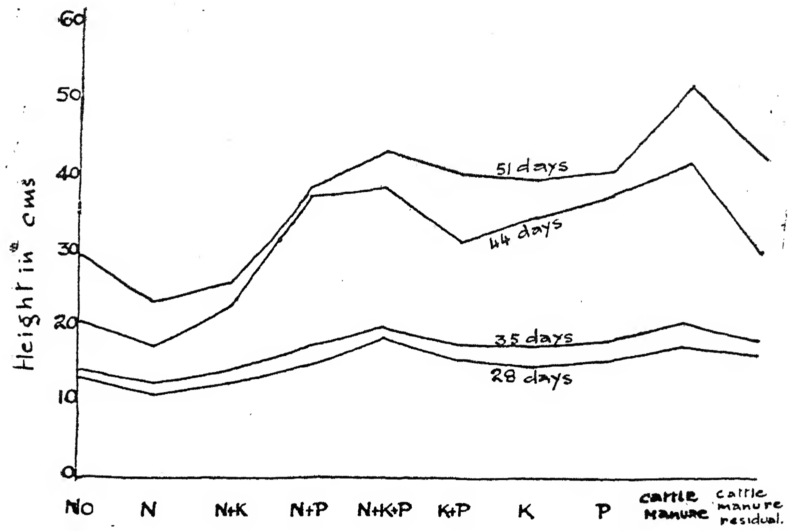
Table I.

Showing periodical measurements of heights in centimeters and yields of plants raised from seeds from the differently manured plots in grm. of dry matter produced.

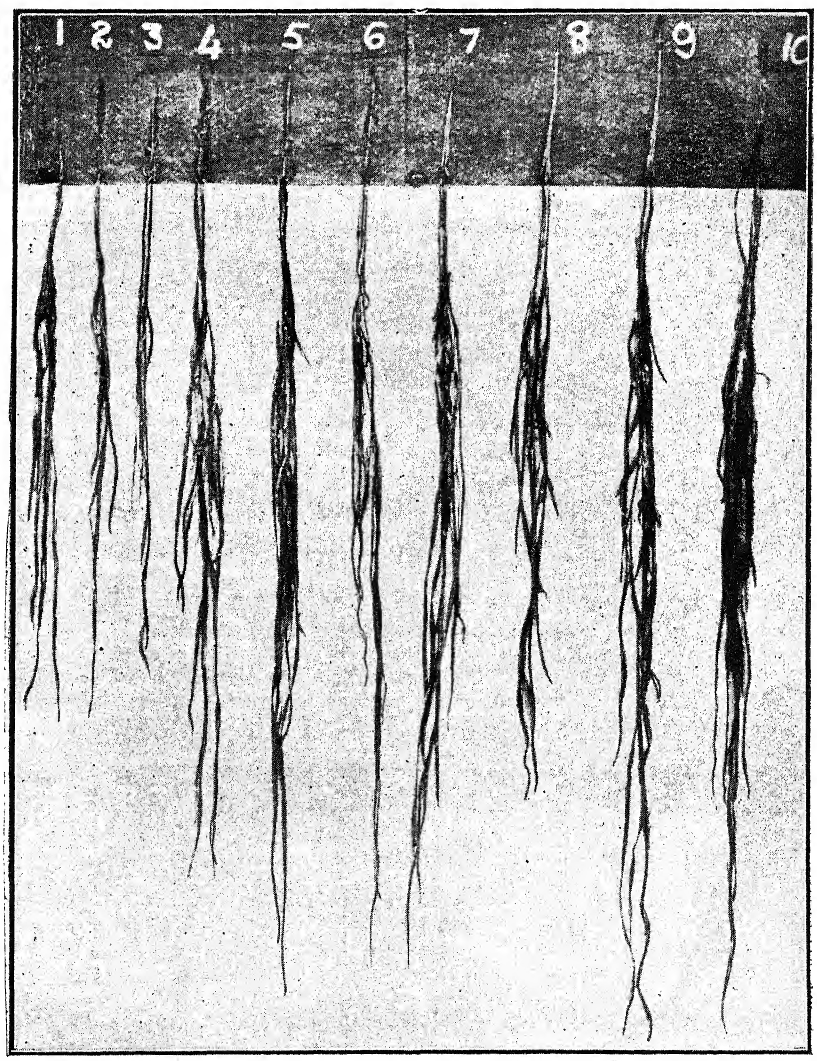
Seed from	Heights of plants in cm. when				Weight of dry matter produced in grm.
	28 days old	35 days old	44 days old	51 days old	
1. No manure plot . .	13·4	14·2	21·0	30·0	0·2608
2. N manure plot . .	11·2	12·7	17·7	23·3	0·1703
3. N+K manure plot . .	12·7	14·3	23·0	26·1	0·1749
4. N+P manure plot . .	15·0	17·7	37·7	38·2	0·5251
5. N+K+P manure plot .	19·0	20·3	38·7	43·7	0·7219
6. K+P manure plot . .	16·0	18·0	31·7	40·9	0·4686
7. K manure plot . .	15·0	17·7	35·0	39·8	0·6346
8. P manure plot . .	16·0	18·7	38·3	42·0	0·6562
9 Cattle manure plot . .	18·3	21·0	42·7	58·0	0·7469
10. Cattle manure (residual) .	17·0	19·0	30·7	48·4	0·6411

Experiment II.

Pot cultures—16th March to 30th May 1924.—The second experiment was also with *ragi*, but the seed used was from that obtained from crop No. 41 of the Permanent Manurial Plots. In this experiment only six different treatments were tested using seed from the no manure, N, N+K, N+P, N+K+P, and cattle manure plots. This experiment lasted for 75 days from the 16th of March to 30th May 1924. The pots were thinned down to 4 plants each. The plants were harvested individually and the dry weight of each plant recorded separately.



1. Heights of Ragi seedlings from seeds from different permanent manurial plots at different stages of growth.



2. Ragi seedlings grown from seeds from differently manured plots.

[redacted]

TABLE II.

Showing average heighs in cm. of ragi plants at the time of harvest and weights of dry matter produced.

Seed from plot	Average height in cm.	Dry weight of plants in grammes								Average per plant
		1	2	3	4	5	6	7	8	
No . . .	84·4	1·139	1·457	1·551	1·936	2·118	2·472	3·273	..	1·992
N . . .	84·9	1·756	2·084	2·553	3·334	3·471	5·321	..	..	3·087
N+K . .	85·7	1·563	1·625	2·366	2·873	3·092	3·550	..	..	2·511
N+P . .	87·3	1·559	2·009	2·516	2·768	2·952	3·093	3·355	3·718	2·747
N+K+P .	91·3	1·818	1·860	2·209	2·724	2·737	3·142	3·439	4·855	2·854
Cattle Manure .	90·5	1·900	2·816	2·967	3·142	4·095	4·119	5·116	..	3·451

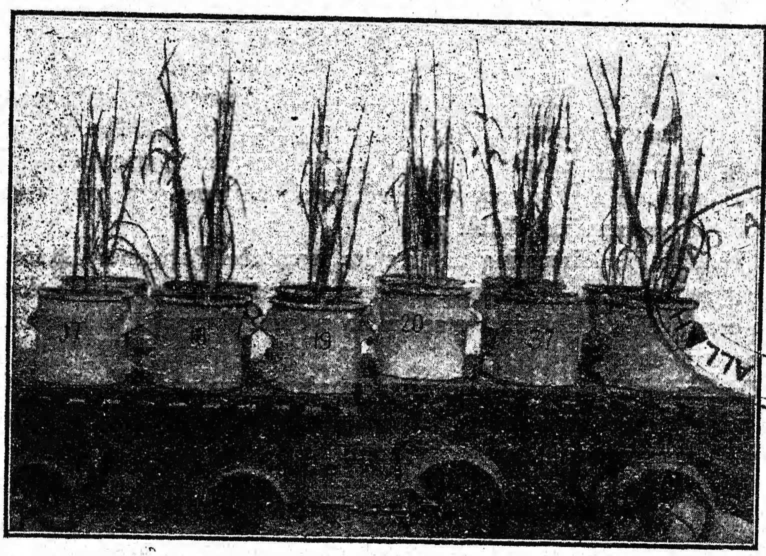


FIG. 1. *Ragi* plants (crop 41) from the seed from plots receiving no manure, N, N+K, N+P, N+K+P C. M. (continuous); (from left to right).

EXPERIMENT III.

Pot cultures—11th March to 15th May 1924.—*Pani varagu*—A third experiment was made on lines exactly similar to the second, the only difference being that the seed under test in this case was *pani varagu* crop No. 42 of the Permanent Manurial Plots. While the experiment was in progress the pots growing the "Cattle manure seed" were accidentally broken. The plants were transferred to another pot but they died after a few days.

TABLE III.

Showing heights in cm. and dry matter in grm. of pani varagu plants (crop No. 42.)

Nature of seed	Height in cm.	Weight of dry matter in grm.
No.	57·3	1·35
N	79·0	2·44
N+K	68·7	2·10
N+P	73·3	1·90
N+K+P	77·2	2·60
Cattle Manure	Pots accidentally broken during the experiment.	

It will be seen that the effect of manurial treatment given to the parent crop persisted in the seed and was manifested when the seed was germinated and allowed to grow into a crop. The amount of dry matter obtained from the growth of "Cattle manure seed" was the largest, that from "Mineral manure seed" came next and that from the "No manure seed" was the least. The dry matter produced from seed from plots receiving partial combinations of manures varied according to the manurial treatment given to the parent crop. The crop from seed from plots receiving phosphate alone or phosphate in combination with nitrogen or potash was greater than the crop obtained from seed from plot receiving nitrogen and potash in combination (Table I).

Dr. Norris[1], while discussing the results from the Permanent Manurial Plots at Coimbatore, has drawn attention to the fact that phosphate is the chief limiting factor in crop yields. This factor seems to operate through the seed on to the succeeding crop as well.

It will avoid confusion and will help towards a clear understanding of the main issue if only three cases, namely "No manure seed," "Mineral manure seed," and "Cattle manure seed" are considered.

TABLE IV.

Showing percentage increases over "No manure seed" crop, of those from "Mineral manure seed" and "Cattle manure seed."

Crop from	Per cent. increase over crop from "No manure seed"		
	Ragi crop 38	*Ragi* crop 41	*Pani varagu* crop 42
"No manure seed"	....	....	....
"Mineral manure seed"	177·0	43·2	92·6
"Cattle manure seed"	188·5	73·2	Figure not available.

[1]Norris R. V. *Loc. Cit.*

It will be seen that in the case of *ragi*, crops 38 and 41, the application of complete mineral manure to the parent crop produced a seed which on being sown gave 177 per cent. and 43·2 per cent. increase respectively over that from " No manure seed " in the second generation crop and that the application of cattle manure to the parent crop produced a seed which gave an increase of 188·5 per cent. and 73·2 per cent. of crop respectively over that from the " No manure seed.". Similarly, *pani varagu* seed from the complete mineral manure plot gave 92·6 per cent. increase of crop over that from " No manure seed." As for *pani varagu* seed from the cattle manure plot, unfortunately, no figures are available as the plants were accidentally lost while the experiment was in progress.

The results of the three experiments having shown that, both from the point of view of growth and yield of dry matter, the effect of manurial treatment given to a crop persists in the seed and exhibits itself in the next generation, the next point for consideration is whether the observed increases in the yield are statistically significant. Table V gives figures for the individual plant yield, of crops from " Cattle manure seed " and " No manure seed " relating to the second experiment (Table II) and the standard deviations worked out by Student's as well as by Bessel's method. The statistical significance is in favour of the view that the increases are not due to mere chance but to the effect left in the seed of the treatment given to the parent crop.

TABLE V.

Showing the air-dry weights of individual ragi plants.

Plant No.	WEIGHTS OF INDIVIDUAL PLANTS RAISED FROM		
	" Cattle manure seed " grams	" Mineral manure seed " grams	" No manure seed " grams
1	1·90	1·82	1·14
2	2·82	1·86	1·46
3	2·97	2·21	1·55
4	3·14	2·72	1·94
5	4·10	2·79	2·12
6	4·12	3·14	2·47
7	5·12	3·44	3·27
Total .	24·17	17·98	13·95
AVERAGE .	3·45	2·57	1·99

Statistical significance of yields by Student's Method :—

Odds in favour of "Cattle manure seed" plants over "No manure seed" plants are overwhelming, as $\frac{\text{Mean of differences}}{\text{Standard deviation}}=\frac{1{\cdot}46}{0{\cdot}39}=Z=3{\cdot}7$

Odds in favour of "Mineral manure seed" plants over "No manure seed" plants are 39 2 :1 as $\frac{\text{Mean of differences}}{\text{Standard deviation}}=\frac{0{\cdot}58}{0{\cdot}55}=Z=1{\cdot}05$

Statistical significance of yields by Bessel's Method :—

The standard deviation of the weight of any individual plant raised from "Cattle manure seed" from its mean . . . . 1·07

The standard deviation of the weight of any individual plant raised from "No manure seed" from its mean . . . . 0·72

The standard deviation of—

difference of the weight of "Cattle manure seed" plant from its mean } *Minus* { difference of the weight of "No manure seed" plant from its mean.

$$=\sqrt{\frac{(1{\cdot}07)^2+(0{\cdot}72)^2}{7}}$$

$$=\ 0{\cdot}47$$

The average weight of "Cattle manure seed" plant } *Minus* { The average weight of "No manure seed" plant $=1{\cdot}46$

$$\frac{1{\cdot}46}{0{\cdot}47}=3{\cdot}1$$

A quotient of 2·1 is enough to prove the statistical significance of the results.

So far only the amount vegetative growth has been considered. The next step in the investigation was to see whether this peculiar effect continued till the crop ripened and contributed to increase the grain yield in the next generation.

Experiment IV.

Pot cultures 18th Nov. 1924 to 5th Feb. 1925.—Pani varagu Crop No.42 from the Permanent Manurial Plots was the grain used in this experiment. About a hundred seeds were sown in each pot, 16 inches in diameter. When the seedlings were a few days old they were thinned down to 16 plants in each pot. The results are given in the Table below.

Table VI.

Showing yields of ear heads and straw from pani varagu seeds of crop No. 42.

Crop from	No. of plants	Weight of ear heads in grm.	Weight of straw in grm.	Total dry matter in grm.	Calculated yield of ear heads per 100 plants	Per cent increase over "No manure seed"
"No manure seed" . . .	40	5·13	2·78	7·91	17·7	..
"Mineral manure seed" . .	48	5·74	2·89	8·63	23·5	32·8
"Cattle manure seed" . .	42	6·30	2·96	9·26	35·0	100·7

The seed from the complete mineral manure plot and the cattle manure plot gave 32·8 per cent. and 100·7 per cent. increase respectively on the weights of ear-heads over the crop raised from the seed from the no manure plot.

Experiment V.

Cultures in small plots:—August-November 1925. In the experiments so far considered the plants were grown in pots in the pot culture house. Pot cultures, however carefully planned and carried out, are too artificial to stand comparison with natural conditions of plant growth and therefore cannot admit of generalisations. A negative result in a pot culture test may very often prove to be so in any other form of test, but a positive result in a pot test need not necessarily mean it would be confirmed under other conditions of experiment. In this experiment, therefore, the disabilities of pot cultures were reduced to a minimum by growing plants in small plots 4 square feet in area. Twelve pits measuring $2' \times 2' \times 1'$ each were dug in the ground. The pits were filled with the experimental soil which was passed through a 2 mm. sieve and thoroughly mixed before it was put into the pits. No manuring was done. The analysis of the soil is given below.

	Per cent.
Nitrogen	0·059
Phosphoric acid soluble in 1 per cent. citric acid (P_2O_5)	0·028
Potash soluble in 1 per cent. citric acid (K_2O)	0·032

The plots were sown with one hundred seeds each of *ragi* Crop No. 41, from the *No manure*, *Mineral manure* and *Cattle manure* plots. There were thus four plots for the seed from each treatment. The plots were sown thickly, the object being to give ample opportunity for the inherent capacity of the seed to extract food materials from the soil. Differences in the heights of plants as in the case of pot culture experiments were noticed, but they were not so great as in pot cultures. The plants from the "No manure seed" were the first to put forth ear-heads. Next came those from the "mineral manure seed" and the last to put forth ear-heads were those grown from the "Cattle manure seed." It was originally arranged to allow the ear-heads to ripen and then harvest straw and grain separately. There was, however, a risk of damage from birds and squirrels and so the plots were harvested although many ear-heads of the plants from the "Cattle manure seed" did not fully develop and ripen. Care was, however, taken to collect the ear-heads and straw separately. The plants at the edges of the plots were not included in the harvest. The plants were dried in the sun till constant in weight and the results are given below.

TABLE VII.

Showing yields of ragi *straw and ear-heads from plots sown with "No manure seed," "Mineral manure seed" and "Cattle manure seed."*

Number of plot	Number of plants	Number of ear-heads	Weight of ear-heads	Weight of straw	Total weight of straw and ear-heads
Plots growing "No manure seed."					
			grm.	grm.	grm.
1	60	12	2·55	33·0	35·55
2	48	25	17·40	73·0	90·40
3	64	49	9·75	89·5	99·25
4	24	10	4·40	52·0	56·40
Total	196	96	34·10	247·5	281·60
AVERAGE PER PLANT	..	..	..	..	1·44
Plots growing "Mineral manure seed."					
1	40	21	18·35	89·00	107·35
2	58	24	9·85	94·00	103·85
3	70	37	8·12	78·00	86·12
4	50	33	22·60	128·50	151·10
Total	218	115	58·92	389·50	448·42
AVERAGE PER PLANT	..	..	..	..	2·06
Percentage increase over "No manure seed" plants.	..	..	..	..	43·05
Plots growing "Cattle manure seed."					
1	36	17	10·62	62·00	72·62
2	46	24	19·20	130·50	149·70
3	62	44	21·30	109·00	130·30
4	51	30	7·20	72·00	79·20
Total	195	115	58·32	373·50	431·82
AVERAGE PER PLANT	..	..	..	..	2·21
Percentage increase over "No manure seed" plants.	..	..	..	..	53·47

The statistical significance of the total yields of straw and ear-heads by the Student's method is worked out below :—

Crop from " Cattle manure seed " A.	Crop from "No Manure seed " B.	A-B	$(A-B)^2$
72·62	35·55	37·07	1374·2
149·70	90·40	59·30	3516·5
130·30	99·25	31·05	967·2
79·20	56·40	22·80	519·8
		150·22	6377·7
$\frac{\text{Mean difference}}{\text{Standard deviation}} = \frac{37·56}{13·57} = 2·77$; odds=116/1.			

The odds in this experiment are 116:1 in favour of increase of crop from the " Cattle manure seed " over that from the " No manure seed."

All the plants from each of the four plots were mixed up. There were thus three lots of plants for the three kinds of seeds. Random samples in lots of 5 each were drawn and weighed and the significance of these was worked out by Bessel's formula as shown below :—

TABLE VIII.

Showing weights of plants in lots of 5 each taken at random.

" No manure seed "	" Cattle manure seed "	Mineral manure seed "
8·05	6·75	7·18
4·80	4·25	8·05
5·45	7·85	12·40
2·32	6·40	11·95
6·90	5·25	7·05
10·35	10·30	9·75
7·40	13·15	6·95
7·75	10·18	4·68
6·92	14·98	6·42

Showing weights of plants in lots of 5 each taken at random—concld.

"No manure seed"	"Cattle manure seed"	"Mineral manure seed"
6·18	10·25	6·00
3·90	13·78	8·72
4·52	15·50	10·78
4·85	5·60	4·38
4·02	11·95	3·92
5·48	6·50	6·45
6·65	17·62	3·50
3·65	3·85	4·32
5·62	7·68	3·95
3·05	7·80	4·01
8·82	5·75	3·45
5·98	6·65	2·98
6·12	4·15	5·40
4·22	5·72	3·25
5·10	5·15	9·10
10·80	8·60	8·92
6·15	6·32	11·85
3·78	7·25	19·20
	7·12	11·25
	3·98	8·20
		5·15
		11·10
		4·45
AVERAGE 5·88	8·29	7·34
Per cent. increase over "No manure seed"	40·9	2·48

Standard deviation of the weight of any lot of 5 plants raised from "Cattle manure seed" . . . . 0·696

Standard deviation of the weight of any lot of 5 plants raised from "No manure seed" . . . . 0·404

The standard deviation of—

difference of the weight of any individual lot of 5 "Cattle manure seed" plants from its mean	minus	difference of the weight of any individual lot of 5 "No manure seed" plants from its mean	$=0{\cdot}805$
The average weight of a lot of 5 "Cattle manure seed" plants	minus	The average weight of a lot of 5 "No manure seed" plants	$=2{\cdot}41$

$$\frac{2{\cdot}41}{0{\cdot}805} = 2{\cdot}99$$

Therefore the results are statistically significant.

Here again it is shown that the increase of crop from "Cattle manure seed" over that from "No manure seed" or "Mineral manure seed" was not accidental but was due to the inherent capacity of the seed.

Experiment VI.

This experiment was carried out in small plots as before with wheat, Crop No. 45 from the Permanent Manurial Plots. The methods of experiment were the same as in the case of the previous one with *ragi*, the only modification being that the different seeds were sown in adjacent lines in each plot instead of assigning a single plot for each kind of seed. The results are shown below :—

	Plants raised from		
	"Cattle manure seed"	"Mineral manure seed"	"No manure seed"
No. of plants	28	42	25
Total weight of plants in grammes . .	85·92	91·41	48·90
Average weight of one plant in grammes .	3·07	2·18	1·96

It will be seen that here again the "Cattle manure wheat" was distinctly superior to the "No manure wheat"; but in contradistinction to the results with millets, *ragi* and *panivaragu*, the increase of crop from "Mineral manure seed" over that of "No manure seed" was not significant at all.

Experiment VII.

Field scale Experiment with wheat Crop No. 45 from the Permanent Manurial Plots—23-IX-1925 to 5-III-1926. The results of experiments in small plots having confirmed those in pots, an experiment was carried out with wheat on the field scale in F. No. 64 Central Experiment Station on a small plot measuring 38·6 feet by 40 feet. We are indebted to Mr. Sa-a-dat Ullah Khan, the Superintendent, for affording facilities for the experiment. The crop was grown in lines, the arrangement being in the order, "No manure," "Mineral manure" and "Cattle manure" seeds. These were repeated nine times. At the time of harvest, the end rows were rejected and only the interior rows were harvested. A complete statement of the results obtained and their statistical significance will be found in Table IX.

TABLE IX.

Showing results of line harvests of wheat in F. No. 64.

Number of plants per line	Total weight of crop	Total weight of grain	Weight of grain per plant
PLANTS RAISED FROM "NO MANURE SEED"			
	grm.	grm.	grm.
33	582·5	191·5	5·8
42	1084·5	337·0	8·0
30	1139·5	353·5	11·8
42	835·5	310·0	7·4
34	569·0	203·5	6·0
38	858·0	302·5	7·9
33	909·0	349·5	10·6
Total 252	5978·0	2047·5	
PLANTS RAISED FROM "MINERAL MANURE SEED"			
44	918·0	312·5	7·1
38	938·0	320·0	8·4
41	1246·5	437·0	10·7
32	631·0	204·0	6·4
33	537·5	180·5	5·5
35	846·5	314·5	9·0
31	711·5	270·5	8·7
Total 254	5829·0	2039·0	
PLANTS RAISED FROM "CATTLE MANURE SEED"			
36	1058·0	370·0	10·3
38	1326·5	418·5	11·0
38	1026·0	371·0	9·8
41	926·0	354·5	8·6
37	591·5	240·5	6·5
43	1077·0	401·5	9·3
37	790·5	273·5	7·4
Total 290	6795·5	2429·5	

% increase of grain from "Cattle manure seed" over "No manure seed" . . 9·4
% increase of grain from "Cattle manure seed" over "Mineral manure seed" . . 12·7

Here it is again seen that " Cattle manure seed " was the best giving an increased yield of grain of 9·4 per cent. and 12 7 per cent. respectively over " No manure seed" and " Mineral manure seed." Of the seven repetitions, the yields of grains from two lines in the case of " No manure seed " were higher than the corresponding lines of " Cattle manure seed." If the two abnormal values are cut out and their statistical significance worked, the odds in favour of increase of grain from "Cattle manure seed " are as 40 : 1.

There was some shedding and bird damage which could not be estimated. If, however, the straw yields alone from the seven lines are considered, the increase of straw from " Cattle manure seed " over " No manure seed " is statistically significant.

Here again it will be noticed, unlike the case of millets, *ragi* or panivaragu, the yield of grain and straw from the " Mineral manure seed " was not more but even lower than that from the " No manure seed." It may be that the effect of mineral manure on seed varies with crops.

The discussion of the results of these experiments may be deferred till the results of the experiments on the nutritive values of the grains for animals are considered.

II. Experiments on animal nutrition.

Ragi and wheat grains from the same crop as used in the vegetation experiments mentioned in Part I of this paper were submitted to Lieut. Col. R. McCarrison who made an independent but complemental study of their nutritive and Vitamin values.

His experiments with millet (*ragi*) were carried out in 1923, the results of which were published in the *British Medical Journal*[1]. The results of his experiments with wheat carried out in 1925-1926 are being published separately.[2] We are indebted to him for permission to refer to them here and to reproduce some of his charts. For full details the original papers should be consulted.

NUTRITION TESTS WITH MILLET (RAGI)—CROP NO. 38 FROM THE PERMANENT MANURIAL PLOTS.

The object of the experiments was to ascertain the relative effect of " No manure, " " Mineral manure " and " Cattle manure " *ragi* in preventing loss of weight in pigeons when fed on a basal diet consisting of rice with a deficiency of Vitamin B, suitable protein and inorganic salts. Adult pigeons in groups of 6 each were used. The experiment was continued to the death of all birds from

[1] McCarrison, R. *Brit. Med. Jour.* March 29, 1924.

[2] McCarrison, R. *Indian Jour. Med. Research,* October 1926.

polyneuritis or other causes. The results are graphically shown in Fig. 2, Chart A, where for the sake of clearness the weight curves are represented by straight lines.

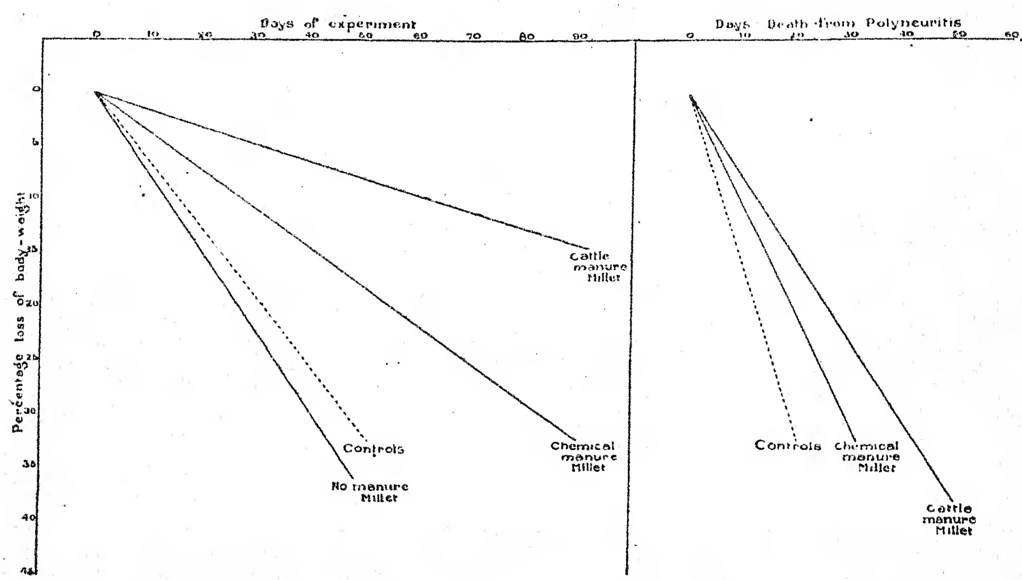


Chart A. Chart B.

FIG. 2. Showing the results of nutritional tests with millet from the different manured plots (by courtesy of Lieut.-Col. R. McCarrison).

Figures for the different groups showing the loss of weight and days within which death occurred are given below in a concise form.

Nature of group	Average per cent. loss of initial body weight in days	Average period in which death occurred
Groups receiving Basal diet only	37·7	Days 51
Group receiving Basal diet *plus* "Cattle manure *ragi*."	22·4	92
Group receiving Basal diet *plus* "Mineral manure *ragi*."	37·4	90
Group receiving Basal diet *plus* "No manure *ragi*."	40·9	48

The addition of "Cattle manure *ragi*" to the basal diet considerably lowered the loss in body weight and increased the average period in which the death of the pigeons occurred. The addition of "Mineral manure *ragi*" to the basal diet did not diminish the loss in weight but considerably delayed the approach of death. In distinct contrast to the two above, the addition of "No manure *ragi*" to the basal diet resulted in an increase in the loss of body weight and shortening of the period within which the pigeons died. Thus *ragi* from the No manure plot was found not only inferior to "Cattle manure" and "Mineral manure" *ragis* in its nutritive value but was actually toxic. Taking percentage loss in weight as the basis, the different *ragis* may be assigned the following numerical values of merit.

"Cattle manure *ragi*" is superior to "No manure *ragi*" . .	by 18·5 per cent.
"Cattle manure *ragi*" is superior to "Mineral manure *ragi*" .	by 15·0 ,, ,,
"Mineral manure *ragi*" is superior to "No manure *ragi*" . .	by 3·5 ,, ,,

The superiority of "Cattle manure *ragi*" is further established by the fact that the loss in the body weight of individual pigeons receiving this grain varied between 8·4 per cent. and 33·3 per cent., whereas in the case of the pigeons receiving "Mineral manure *ragi*" the loss ranged from 28·6 to 47·1 per cent.

Chart B in Fig. 2 represents the results of experiments of further tests on the relative Vitamin B values of "Cattle manure *ragi*" and "Mineral manure *ragi*." "No manure *ragi*" could not be tested as its supply was exhausted. The control group receiving basal diet only died of *polyneuritis* in from 13 to 25 days with an average of 21 days. Those of the group receiving basal diet *plus* "Mineral manure *ragi*" died of *polyneuritis* in periods ranging from 14 to 54 days with an average of 33 days, while one died from other causes. In the group receiving basal diet *plus* "Cattle manure *ragi*" two died from other causes and four died from *polyneuritis* in periods ranging from 44 to 54 days with an average of 50 days.

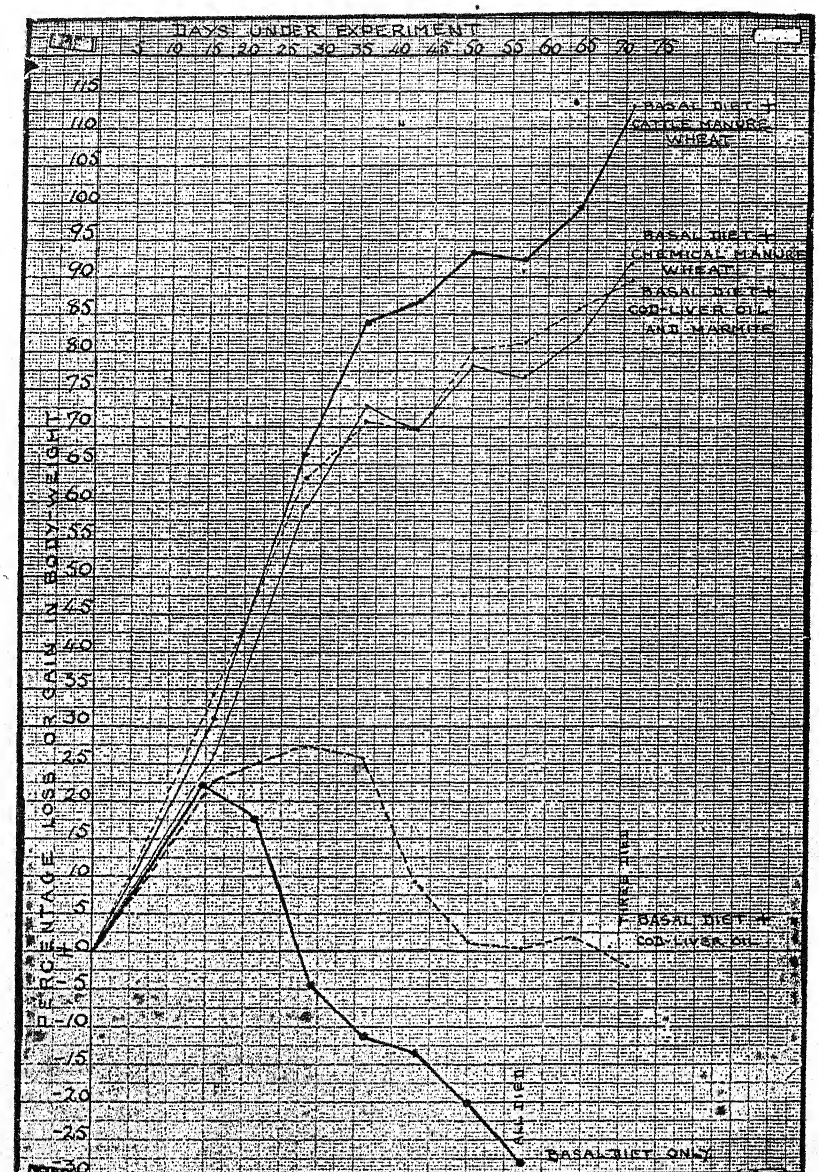
The "Cattle manure *ragi*" was thus shown to be richer in Vitamin B than the "Mineral manure *ragi*" since an equal amount of it delayed for a longer time the onset of *polyneuritis* in an equal aggregate weight of pigeon.

It should be noted that the relative merits of the three *ragis*, as revealed by the nutritional experiments just considered, were in the same order as was found in the vegetation tests. That is, so far as *ragi* was concerned, the effect of manurial treatment on the seed was similar in regard to its value in plant and animal nutrition. This remarkable agreement between plant and animal experiments is worthy of note.

Experiments with wheat—Crop No. 45.

In this study young albino rats were used. "No manure wheat," "Mineral manure wheat" and "Cattle manure wheat" from Crop No. 45 (Permanent Manurial Plots) were the grains whose Vitamin values were tested. The basal diet consisted of meat residue, purified starch, olive oil and salt mixture. Cod Liver oil as a source of Vitamin A and marmite as a source of Vitamin B were added sepa-

rately or together as required. The results of the experiments are shown graphically in Figs. 3 to 7.



3. Showing the difference in nutritive value between "Cattle manure wheat" and "Chemical manure wheat" (by courtesy of Lt.-Col. R. McCarrison).

It will be seen from Figure 3 that on the basal diet which was very deficient in Vitamin B, the rats grew for a period of only 14 days. Thereafter they lost weight rapidly, developed *polyneuritis* and all of them died within 60 days.

The group of rats on basal diet *plus* Cod Liver oil was not free from *polyneuritis*. The initial period of growth was somewhat prolonged, but later on the body weight fell rapidly. Four animals developed *polyneuritis* between the forty-eighth and fifty-sixth days of the experiment and finally 3 of them died. Two rats survived for 72 days without the appearance of *polyneuritis*.

Thus, the basal diet, whether with or without the addition of Cod Liver oil, did not suffice for growth or for the maintenance of life.

The addition to the basal diet of Cod Liver oil and marmite resulted in much better growth of animals and in complete protection from *polyneuritis*. The animals remained in apparently perfect health throughout the experimental period.

The substitution of Cod Liver oil and marmite by wheat as the sole source of Vitamins A and B resulted in as good as, and even slightly better growth than with Cod Liver oil and marmite. Whole wheat is, therefore, a rich source of growth promoting factors. It will, however, be noted that " Cattle manure wheat " was distinctly superior to " Mineral manure wheat " by about 10 to 17 per cent. in this respect.

The Charts in Figures 4, 5 and 6 represent the results of further experiments to test the general statement that wheat is deficient in Vitamin A.

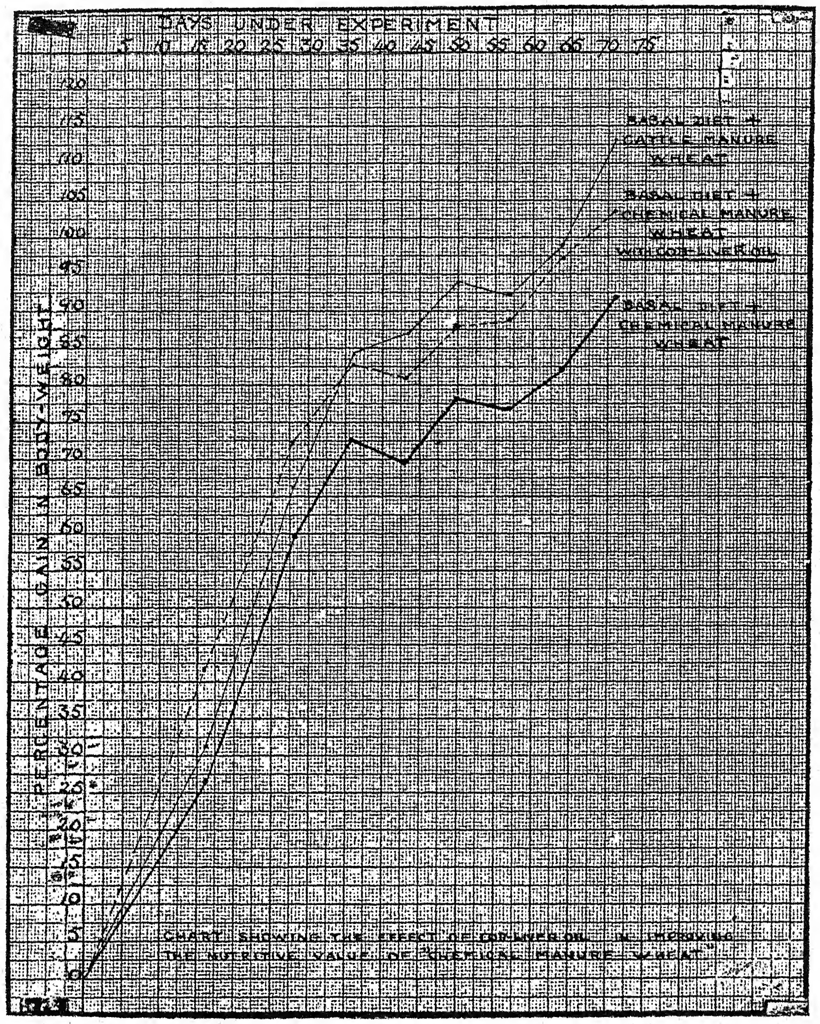


FIG. 4. Showing the effect of addition of Cod Liver oil in improving the nutritive value of " Chemical manure wheat " (by courtesy of Lt.-Col. R. McCarrison).

The addition of Cod Liver oil to the diet containing Basal diet *plus* " Chemical manure wheat" increased its nutritive value by about 10 to 15 per cent. and caused the growth curve for this diet to approximate closely to that of Basal diet *plus* " Cattle manure wheat." (Figure 4). It is obvious that the Cod Liver oil contri-

buted the necessary growth promoting substances which are apparently lacking in the " Mineral manure wheat " but present in " Cattle manure wheat." Of the growth promoting substances contributed by Cod Liver oil, Vitamin A is perhaps the chief one, though slight amounts of Vitamin B and manganese are also present. " Mineral manure wheat" was, therefore, deficient in certain factors supplied by either " Cattle manure wheat " or Cod Liver oil.

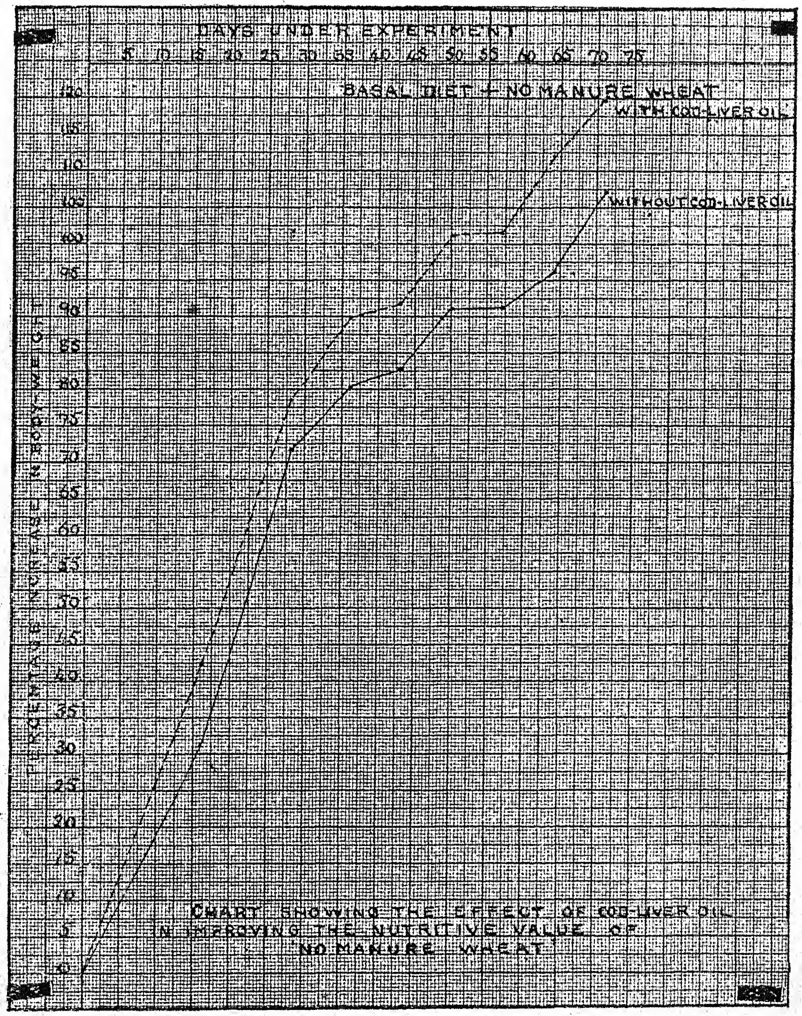


FIG. 5. Showing the effect of Cod Liver oil in improving the nutritive value of " No manure wheat " (by courtesy of Lt.-Col. R. McCarrison).

In figure 5 are shown the results of the addition of Cod Liver oil to the diet containing basal diet *plus* " No manure wheat." Here again the beneficial effect of Cod Liver oil is visible in improving the value of " No manure wheat " and bringing it to or slightly higher than the level of " Cattle manure wheat." It may therefore be stated that "No manure wheat" was lacking in certain growth promoting substances contained in " Cattle manure wheat " and Cod Liver oil.

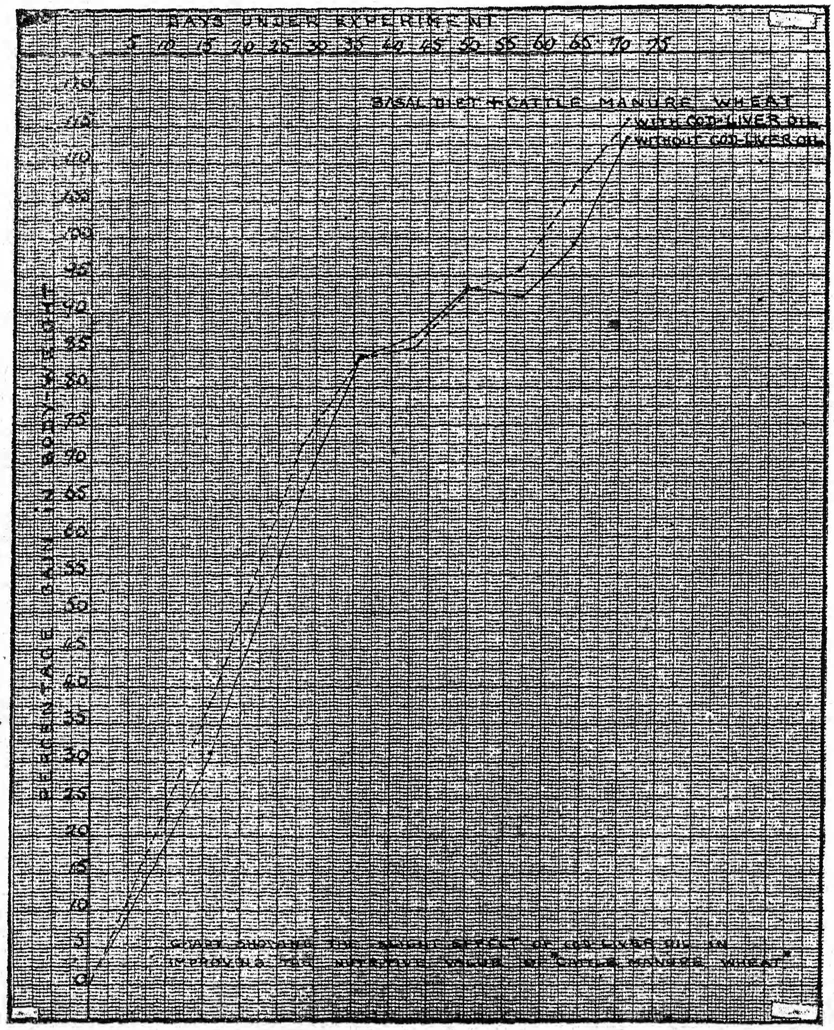


FIG. 6. Showing the slight effect of Cod Liver oil in improving the nutritive value of " Cattle manure wheat " (by courtesy of Lt.-Col. R. McCarrison).

There remains " Cattle manure wheat " to be tested. Figure 8 shows that the addition of Cod Liver oil to a diet containing basal diet *plus* " Cattle manure wheat" made little or no difference. It, may therefore, be assumed that " Cattle manure wheat " supplemented the basal diet with those factors which the Cod Liver oil did.

It is, therefore, justifiable to conclude that " No manure wheat " and " Mineral manure wheat " failed to supply what Cod Liver oil provided and that " Cattle manure wheat " did provide it in an almost equal measure to Cod Liver oil.

According to Lt.-Col. R. McCarrison, the results of these experiments, while affording evidence that the Vitamin A content of wheat is influenced by the manurial treatment of the soil on which the wheat is grown, afford no conclusive evidence of the effect of such manurial treatment on the Vitamin B value of wheat, although a comparison of the results observed would appear to indicate that " Cattle manure wheat " is richer in this factor than " Chemical manure wheat." The results furnished by the experiments with millet indicate that the Vitamin B value of this grain (*ragi*) is markedly influenced by the manurial treatment of the soil."

The relative nutritive values of the three wheats are shown in figure 7.

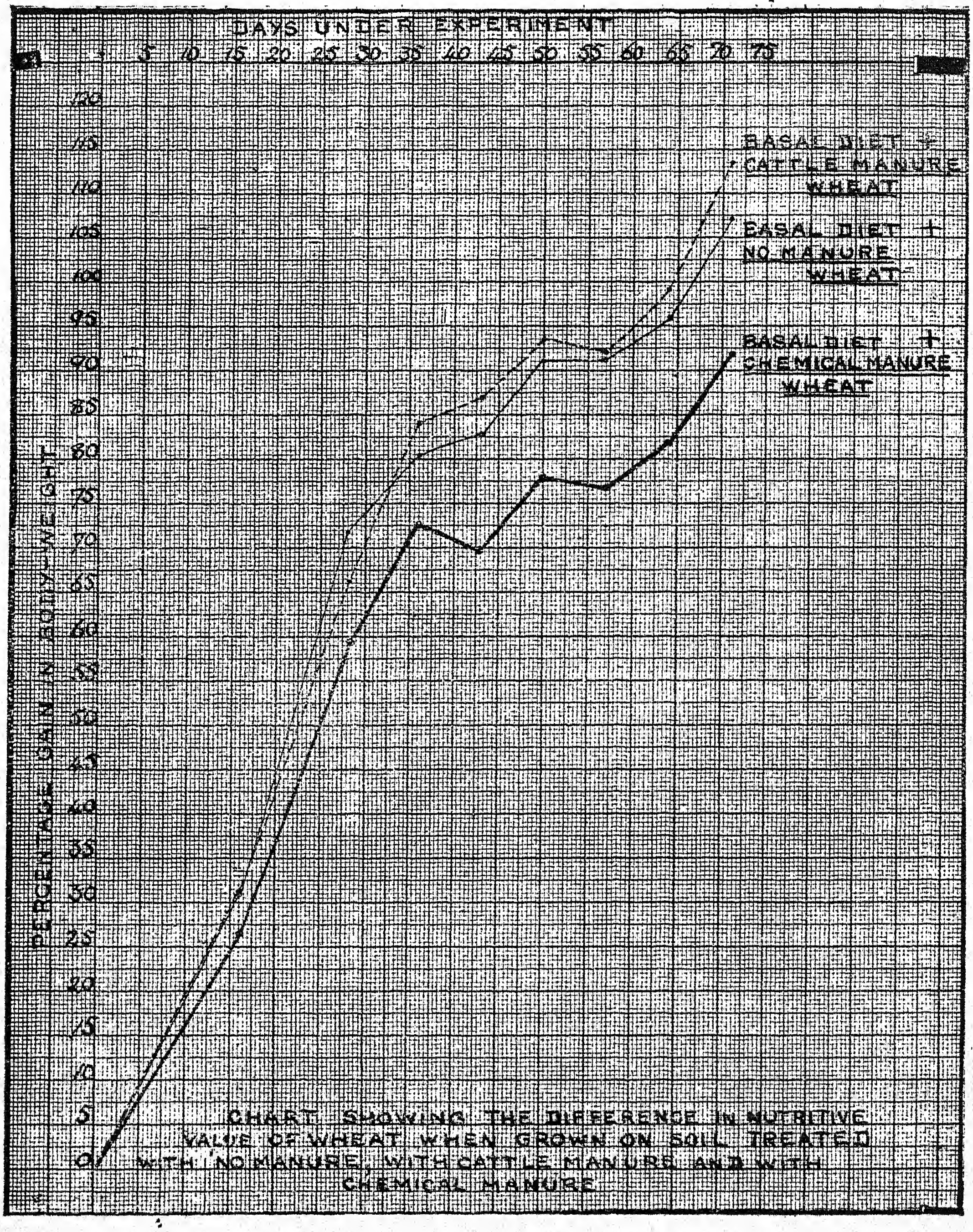


Fig. 7. Showing the difference in nutritive value of wheat when grown on soil treated with No manure, Mineral manure and Cattle manure (by courtesy of Lt.-Col. R. McCarrison).

"Cattle manure wheat" stood first with the highest value. Next in order came "No manure wheat" and the "Mineral manure wheat" came last. The difference between "Cattle manure wheat" and "No manure wheat" was about 6 per cent., while the difference between "Cattle manure wheat" and "Mineral manure wheat" was about 20 per cent., the differences in both comparisons being in favour of "Cattle manure wheat." Here again, it should be noted that the order of superiority is similar to that observed in the vegetation experiments with the wheats.

III. Discussion of the results of plant experiments.

The results of seven independent experiments with three different kinds of grains in pots, small plots and on the field scale show that the effect of manuring a crop persists, is reflected in the seed, and is visible in the vegetation derived from it.

It will be of interest to examine the causes responsible for the differential behaviour of the seeds from the different manured plots.

Judged from the usual analytical standards, the soil on which the vegetation tests were conducted was sufficiently well supplied with available phosphoric acid and potash though rather poor in its nitrogen content.

The first point that would strike one as being responsible for the observed differences in the vegetative and reproductive capacity of the seed, is the weight of the seed and the consequent increase in the reserve material contained therein. The weight of seed and its composition are given in Table X.

TABLE X.

Showing weights of grains from the different manurial plots and their chemical composition.

Crop No. 41 *ragi*. Crop No. 42 *panivaragu*.

Nature of seed	Weight of 100 seeds in grm.	% Composition			Weight of 100 seeds in grm.	% Composition		
		N	P_2O_5	K_2O		N	P_2O_5	K_2O
No manure	0·2883	1·166	0·320	0·378	0·5162	2·015	0·457	0·366
Mineral manure	0·3199	1·014	0·324	0·401	0·6017	1·675	0·792	0·283
Cattle manure	0·3023	1·180	0·650	0·482	0·5699	1·710	0·664	0·245

The weights of "Cattle manure seed" and "Mineral manure seed" are greater than that of the "No manure seed", but the weight of the "Cattle manure seed" which gave the largest yield of crop is less than that of the "Mineral manure seed." There does not, therefore, appear to be any relationship between weight of seed and crop yield. This observation is in accordance with the results of experiments is carried on by this department and elsewhere with light and heavy seed. Again, the chemical analysis of the seed does not reveal any

significant differences except in their phosphoric acid content. The size of the seed is so small, and therefore, the amount of reserve food material is so insignificant that the better growth and yield cannot be attributed entirely to this cause.

The percentage composition of the resulting crop, the total quantity of manurial ingredients removed by it from the soil and calculated amount of manurial ingredients absorbed by one gramme of each of the different seeds are given in table XI.

TABLE XI.

Showing yields of dry matter, analyses of crop, total plant food ingredients removed from the soil, and the assimilation value due to the vigour of seeds from the differently manured plots.

No.	Nature of seed	Relative crop yield from the original Permanent Manurial plots lb.	Relative crop yield when the seed from the different plots is grown in pots grm.	Percentage composition of the crop from pots			Total calculated mineral matter removed by the crop from the soil in the pot grammes			Calculated amounts of manurial constituents assimilated by the crop from 1 gramme weight of seed after deducting the amounts of N, P_2O_5 and K_2O present in the seed grammes		
				N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
				Ragi crop 41.								
1	No manure	468	1·992	3·24	1·09	4·99	0·065	0·021	0·102	20·59	6·75	32·20
2	Mineral manure	796	2·854	3·13	0·85	5·28	0·086	0·024	0·151	28·16	7·69	49·16
3	Cattle manure	1,349	3·451	2·63	0·85	5·38	0·089	0·029	0·183	30·02	9·55	61·83
				Panivaragu crop 42.								
1	No manure	166	1·35	2·99	0·77	4·08	0·036	0·009	0·055	1·16	0·30	1·78
2	Mineral manure	2,486	2·60	2·70	0·59	3·72	0·063	0·014	0·097	1·64	0·37	2·74
3	Cattle manure	2,827		Crop lost			Crop lost			Crop lost		

Considering the chemical composition of the resulting crop, it is seen that the accumulation of nitrogen, phosphoric acid and potash, is, if anything, greater in the crop obtained from the "No manure seed." This indicates that the crop had not to suffer from deficiency of manurial constituents but had apparently failed to assimilate them to the best advantage. Consequently, the amounts of the more important manurial constituents which the plant could extract from the soil had fallen low. The figures for these will be found in the last column of Table XI.

In discussing the nutritive values of the different manurial plots Lieut.-Col. R. McCarrison[1] directs attention to the question of Vitamins and has shown that apart from the mineral content of the seed, there exists a relationship between Vitamin content and nutritive value.

[1] McCarrison, R. *Ind. Journ. Med. Res.*, October 1926.

Attention has been called to the striking similarity in the results of plant and animal nutrition experiments with the seeds from the differently manured plots. Even the growth curves for plants (Fig. 8) exhibit a close resemblance to those of animals (Figs. 3 to 7).

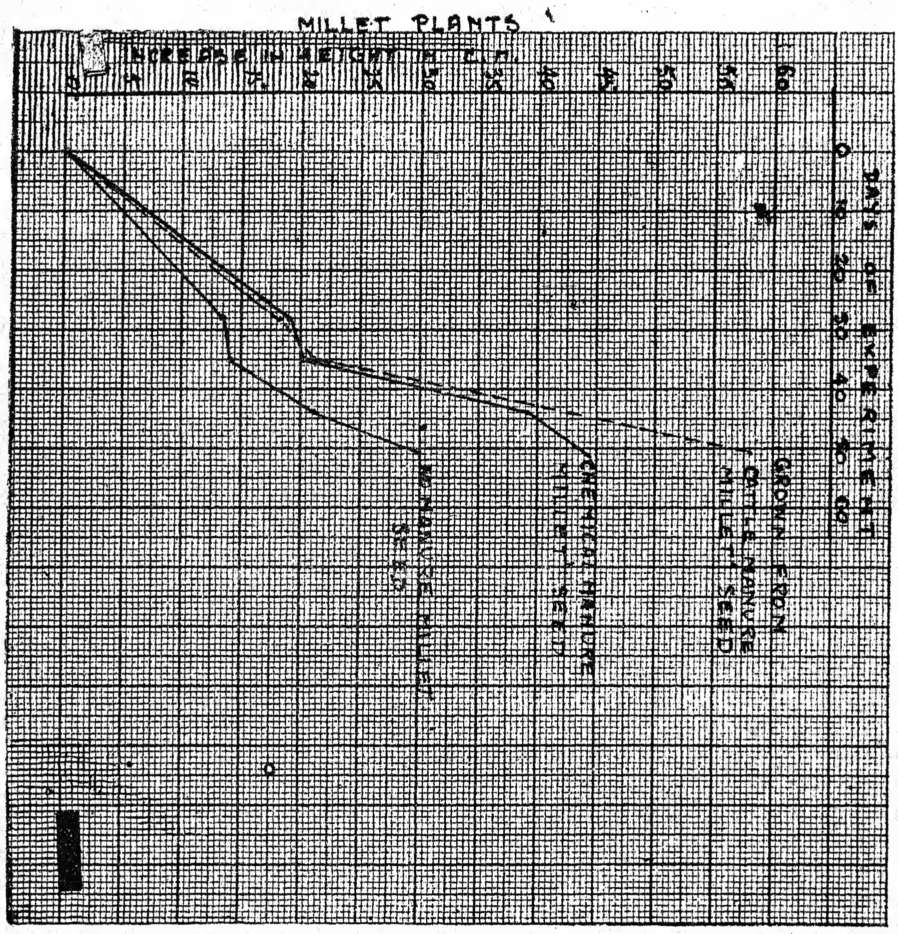


FIG. 8. Showing the growth curves of *raji* plants from the "No manure seed," "Mineral manure seed" and "Cattle manure seed."

Based on this similarity, it may be stated that the seed from a properly manured or correctly fed crop, as in the case of that from cattle manure plot, possessed more vitality and could, therefore, extract from the soil more food material and utilize it; in the case of the seed from a crop that was insufficiently fed or fed on artificial foods, as in the case of the "No manure seed" or "Mineral manure seed,"

it was lacking in *something* which would *vitalise* the young crop. This leads to the question of " Auximones " attention to which was first drawn by Bottomley [1] and later supported by Mockeridge [2], Rosenheim [3] and others. Chief among the contributions are those of Bottomley and Mockeridge who investigated the subject of " Auximones " extensively and have stated that in the bacterial decomposition of organic substances in the soil, certain water-soluble substances named " Auximones " are produced, and that these auximones which are of an organic nature are directly absorbed by plants and are essential for their growth just like "Vitamins" for animals. Bottomley has shown from a microscopic examination that "Auximones" have a marked influence on the size and contents of the cell and especially on the neucleus. This theory has been contested in recent years. Among the principal contributions negativing the " Auximone " theory are those of Clark [4], and Clark and Roller [5] who, while admitting the beneficial action of organic matter in plant nutrition, deny that "Auximones" are essential for the growth and reproduction of green plants and are not prepared to class "Auximones" with the " Vitamins " of animal nutrition.

It is not proposed to enter here into a discussion on the subject whether " Auximones " are essential to plants as " Vitamins " are to animals. It is perhaps difficult to obtain direct experimental proof where green plants are capable of manufacturing "Vitamins" by themselves. At present, we are chiefly concerned with the role of farmyard manure in particular, and of organic matter in general, in the nutrition of the plant, and through it, the animal in so far as they offer an explanation of the experimental facts in animal and plant nutrition. To this extent " Vitamins " and " Auximones " will be considered.

It is realised that the use of the words " Vitamins" or " Auximones " would not be generally acceptable. They are used in this paper for the sake of brevity and intelligible expression of the arguments advanced and are intended to mean activating or vitalising agents and nothing more.

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[1] Bottomley, W. B. The Bacterial Treatment of Peat. *J. Soc. Arts.* 1914. The Significance of Certain Food Substances for Plant Growth. *Ann. Bot.*, 1914. Some Accessory Factors in Plant Growth and Nutrition. *Proc. Roy. Soc.* B. 1914. Some Effects of Organic Growth-promoting Substances " Auximones " on the Growth of *Lemna minor* in Mineral Culture Solutions. *Proc. Roy. Soc.* B. 1915-17. The Isolation from Peat of Certain Nucleic Acid Derivatives. *Proc. Roy. Soc.* B. 1917. A Bacterial Test for Plant Food Accessories (auximones), *Proc. Roy. Soc.* B. 1915-17. The Effect of Nitrogen-fixing Organisms and Nucleic Acid Derivatives on Plant Growth. *Proc. Roy. Soc.* B. 1919. The Growth of *Lemna* Plants in Mineral Solutions and in their Natural Medium. *Ann. Bot.* 1920. The Effect of Organic Matter on the Growth of Various Water Plants in Culture Solution. *Ann. Bot.* 1920.

[2] Mockeridge, F. A. Some Effects of Organic Growth-promoting Substances in the Soil Organisms concerned in the Nitrogen Cycle. *Proc. Roy. Soc.* B. 1917. The Occurrence and Nature of the Plant Growth-promoting Substances in Various Organic Manurial Composts. *Biochem. Jour.* 1920. The Occurrence of Nucleic Acid Derivatives in Nitrogen-fixing Bacteria. *Biochem. Jour.* 1920. Formation of Plant Growth-promoting Substances by Micro-organisms. *Ann. Bot.* 1924.

[3] Rosenheim, Otto. Accessory Factors for Plant Growth. *Biochem. Jour.* 1917.

[4] Clark, N. A. The Soil Organic Matter and Growth-promoting Accessory Substances, *Ind. Eng. Chem.* 1924.

[5] Clark, N. A., and Roller, E. M. " Auximones " and the Growth of the Green Plant. *Soil Science*, 1924.

IV. The role of Organic matter in plant nutrition.

The indirect effects of organic matter on plant growth, in improving the texture and the water holding capacity of the soil, and in forming food for soil bacteria, are well known. The direct effect has not received the attention it deserves owing perhaps to the difficulties involved in the conduct of experiments and the interpretation of the results.

In recent years some work has been done on the subject. Livingston,[1] Bottomley,[2] Rosenheim[3] Mockeridge[4], Wilkins[5] and Robbins[6] have established the fact that small quantities of organic matter exert a beneficial action on plant growth. Mockeridge examined the more frequently used manures, such as leaf mould and stable manure, and has shown that the beneficial action of the manures, in promoting growth of plants, increased with the degree of fermentation or bacterial decomposition of the manures tested and that an extract of 'bacterised peat' produced the largest amount of growth. Her experiments were carried out with the aquatic plants *lemna major and lemna minor*. These were selected for the reason of their being water plants and would, therefore, be under normal conditions of growth in water cultures.

Water plants and their culture are quite different from the normally cultivated crops and so it was considered desirable to experiment with ordinary crops under ordinary conditions in the soil.

Experiment. An amount of farmyard manure enough to supply 50 mg. of nitrogen per kilo of soil was extracted separately with water or 80 per cent. alcohol and the manurial value of these extracts was tested on *ragi* plants in pot cultures with the following results.

Treatment	Total dry matter formed for 12 plants
1. Farmyard manure (fermented)	50·96 grams
2. Synthetic farmyard manure from Peermade (fermented vegetable matter)	52·88 ,,
3. Water extract only from fermented farmyard manure	49·72 ,,
4. Alcoholic extractives from fermented farmyard manure applied in aqueous solution after removing alcohol	44·96 ,,
5. Fresh farmyard manure (whole)	37·8 ,,

The water extract from fermented farmyard manure was as effective as the fermented manure itself. The alcoholic extract was not so good as the water extract. Fresh farmyard manure was much behind the fermented manure.

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[1] Livingston, B. E. Further Studies on the Properties of Some Unproductive Soils, U. S. Dept. Agric. *Bureau of Soils. Bull.* 36, 1907.

[2] Bottomley. W. B. *Loc. Cit.*

[3] Rosenheim, Otto. *Loc. Cit.*

[4] Mokeridge, F. A. *Loc. Cit.*

[5] Wilkins, V. E. Agricultural Research and the Farmer, H. M. Stationery Office, London, 1922.

[6] Robbins, W. J. The Effect of Autolised Yeast and Peptone on the Growth of Excised Corn-root-Tips in the Dark. *Bot. Gaz.* 1922.

Artificial farmyard manure which was nothing but fermented stubble and straw was quite as effective in its manurial value as fermented farmyard manure itself.

These results are in agreement with those of Mockeridge who obtained similar results from fermented and unfermented peat, stable manure and organic composts.

A second experiment was carried out in a similar manner with the extractives and residues of fresh and fermented farmyard manures, the crop used being *ragi*.

Treatment	Total dry matter from 6 plants
1. Water extract from *fermented* farmyard manure	27·26 grams
2. Reside from above after extracting with water	27·00 ,,
3. Water extract from *fresh* farmyard manure	20·16 ,,
4. Residue of *fresh* farmyard manure after extraction with water	5·91 ,,

In regard to the fermented manure, both the extract and the residue were equally effective but in the case of fresh farmyard manure, the extract had a better growth-promoting value than the residue which gave a very low yield of crop.

Mockeridge,[1] as a result of chemical examination of organic manures and composts, has shown that all of them contained nucleic acids and their derivatives and that with increase in the extent of decomposition which the manure undergoes, a correspondingly greater proportion of the original nucleic acid in the undecomposed material resolves into dinucleotides and purine and pyrimidine bases which are responsible mostly, if not entirely, for the growth-promoting effect. On this basis, the better manurial value of fermented farmyard manure when compared with fresh farmyard manure may be explained.

Further, in an attempt to find out whether the bacterial constituents have a direct part in promoting the growth of plants, she tested extracts of autoclaved cultures of *Azotobacter Chroococcum* along with crude nucleic acid derivatives and found that, while the effect of crude nucleic acid derivatives was nearly proportional to the amount of the material added, the response to the *Azotobacter* extract was not commensurate with the quantity added, though increased application had increased effect.

Similar experiments were carried out with autolysed and autoclaved bakers' yeast with similar results.

Yeast is known to contain nucleic acid in fair quantity. Investigation of *Azotobacter* extract has also shown that it contains a carbohydrate radical, phosphoric acid, purine and pyrimidine bases which are seen to promote plant growth.

From a consideration of these results, Mockeridge[2] in a later contribution modified her views on the question of auximones and concluded that the growth-promoting effect of decomposed manures or bacteria is due to nucleic acid derivatives.

[1] Mockeridge, F. A. The Occurrence and Nature of the Plant Growth-promoting Substances in Various Organic Manurial Composts. *Biochem. Journ.* 1920.

[2] Mockeridge, F. A. The Formation of Plant Growth-promoting Substances by Micro-organisms. *Ann. Bot.* 1924.

It should be noted that in all her experiments with the water plants, Mockeridge used large quantities of active substances ranging from 0·5 gram to 4 grams to the litre and so the effect of derivatives of nucleic acid could not be ignored and consequently she could not define the part played by minute organisms like bacteria and yeasts in the supply of growth-promoting factors.

Her experiments were therefore repeated on *ragi* with minute amounts of yeast, the object being to ascertain how far minute applications of cultures, in which the supply of the ordinary manurial constituents, nitrogen, phosphoric acid and potash, is insignificant, contribute to the growth of plants. In the first experiment the effect of a small amount of yeast (about 1·0 gram of wet substance per 15 kilos of soil) was compared with the residues and extracts of fresh and fermented farmyard manures.

Treatment	Total dry matter for 6 plants
1. Water extract from fermented farmyard manure	27·26 grams
2. Residue of fermented farmyard manure after extraction with water .	27·00 „
3. Water extract from fresh farmyard manure	20·16 „
4. Residue of fresh farmyard manure after extracting with water . .	5·91 „
5. Yeast (1·0 gram per 15 kilos of soil). No farmyard manure was added	40·50 „

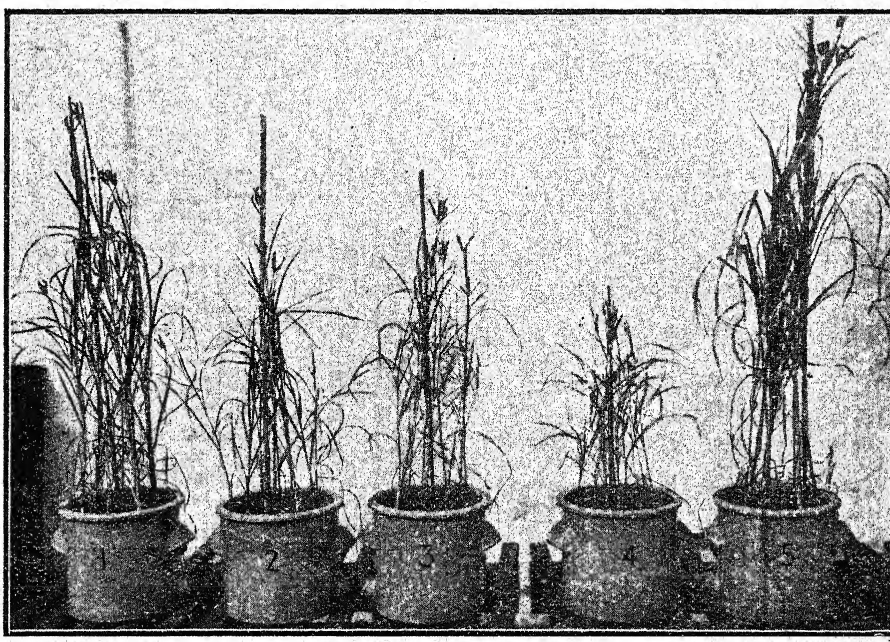

Fig. 9. Showing the growth of *ragi* plants grown under the 5 treatments mentioned above. The numbers on the pots are same as those referred to in the above table.

A small amount of yeast had given the best result; still the amount of yeast might have been sufficiently large to supply manurial constituents or derivatives of nucleic acids.

The next set of experiments was therefore carried out in sand cultures where the effect of yeast was compared against minerals. Crone's normal solution in a highly diluted form was used. The sand used for cultures was not submitted to any special treatment. The experiments were carried out with wheat and *cholam*. Two milligrammes of wet yeast were added to each pot which contained 1 kilo of sand. The yeast contained 0·000050 gram of nitrogen and 0·00004 gram of phosphoric acid.

Treatment	WHEAT	*Cholam*
	Average weight per plant	Average weight per plant
	grm.	grm.
Sand only	0·321	0·34
Sand *plus* Crone's solution in a highly diluted form	0·290	0·33
Sand *plus* Crone's solution *plus* 0·002 gram wet live yeast per kilo of sand.	0·498	0·43
Sand *plus* 0·002 gram wet live yeast per kilo of sand	0·413	....
Sand *plus* 0·004 gram wet live yeast per kilo of sand	....	0·71
Sand *plus* autoclaved yeast ·002 gram per kilo of sand	0·340	....
Sand *plus* Crone's solution *plus* ·002 gram autoclaved yeast per kilo of sand.	0·472	0·37

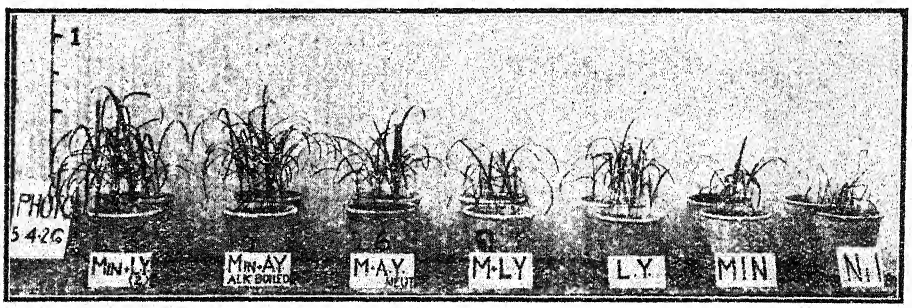

FIG. 10. Effect of Yeast on *ragi*.

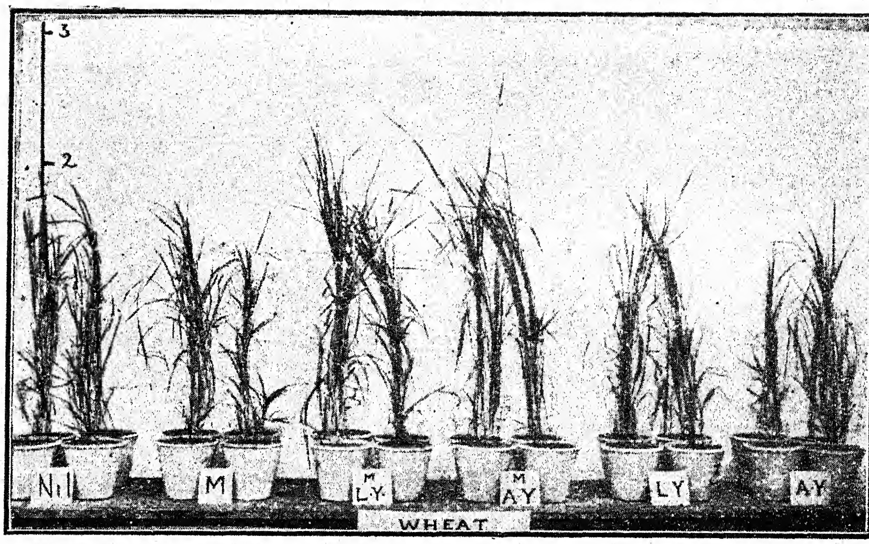

FIG. 11. Effect of Yeast on wheat.

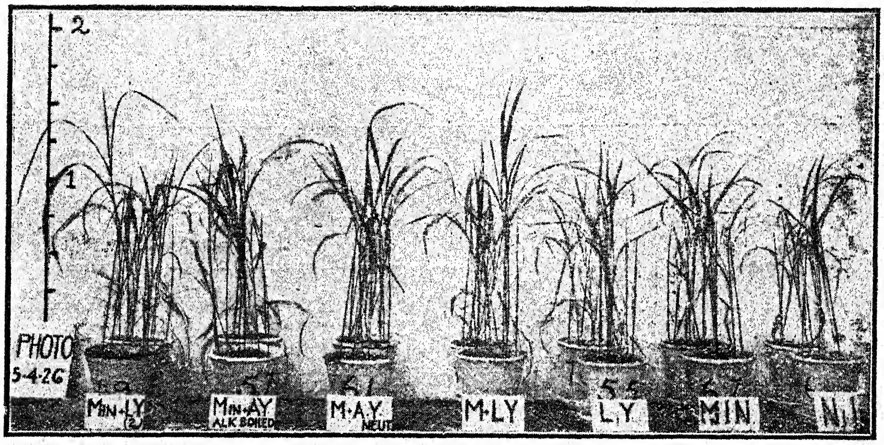

FIG. 12. Effect of Yeast on *cholam*.

Nil = Sand only.

M or Min = Sand and Minerals.

L. Y. = Sand and Live Yeast.

A. Y. = Sand and Autoclaved Yeast.

Similar experiments were carried out with different crops with the following results. The yeast was analysed and an amount of nitrogen and phosphoric acid equivalent to the yeast added was given to the pots which received no yeast.

Crop	Dry matter for 6 plants in grm.		
	Control (soil only)	Soil 0·002 grm. of wet yeast per kilo of soil	% increase over control
Raji (*Eleusine coracana*)	12·45	15·14	21·6
Cumbu (*Pennisetum typhoideum*) . .	21·44	25·90	20·8
Panivaraju (*Panicum miliaceum*) . .	3·39	5·77	70·2
Cholam (*Andropogon Sorghum*) . . .	8·63	11·74	36·0
Tomato (*Lycopercicum esculentum*) yield of fruit.	5·60	9·25	65·2

Another experiment with *ragi* was carried out in small plots $2' \times 2' \times 1'$ in quadruplicate. 0·002 grm. of wet yeast grown on *cholam* malt extract was added per kilo of soil and the nitrogen and phosphoric acid were compensated for by the addition of equivalent amount of these constituents in the form of ammonium sulphate and superphosphate in the control plots. The results are given below :—

Plot No.	Treatment Yeast (0·002 grm. per kilo of soil)		Treatment No Yeast	
	No. of plants excluding those at the edges	Wt. of crop excluding that of plants at the edges	No. of plants excluding those at the edges	Wt. of crop excluding that of plants at the edges
		grm.		grm.
1	60	17·35	60	14·50
2	60	42·50	60	26·50
3	60	60·50	60	31·00
4	60	31·00	60	16·65
Total .		151·35		88·65

% Increase of yeast over no yeast = 93·3
Mean difference of yeast *minus* no yeast = 15·4
Standard deviation = 9·08

$\frac{\text{Mean difference}}{\text{Standard deviation}} = 1·7$ Odds = 32·1 in favour of yeasted plot.

The effect of yeast, live or autoclaved, is clearly visible. The better growth and increase in crop production could not have been due to the effect of the ordinary manurial constituents, especially in the small plots where the number of plants was too large. Firstly the quantity of yeast added was so small, and secondly, the equivalents of nitrogen and phosphoric acid were added in the form of ammonium sulphate and superphosphate. It could not also be due entirely to the effect of nucleic

acid radicals, purine and pyrimidine bases, for here again the quantity of these substances added through the agency of yeast would appear to be too insignificant to be effective to the extent observed. If minute amounts of nucleic acid derivatives were responsible for the stimulation then they must be the "Auximones" of Bottomley.

How then did the yeast benefit the plants? It would appear that as a result of the disintegration of the yeast in the soil the active principle — by whatever name it is called — was liberated and made available for absorption by the plant.

It is well known that animals generally obtain their "Vitamins" from plants. It has been established that fermented organic matter provides growth-promoting substances for plants. Yeast is known to contain "Vitamins" which in small quantities are beneficial to animals. The results of our experiments have shown that minute quantities of yeast stimulate growth and reproduction of plants. It seems, therefore, reasonable to suppose that a certain active constituent — whether it is called "Auximone," "Vitamine," or accessory food factor, whether it is organic or inorganic in nature, and whether it is the same or different for plants or animals — is passed to the animal through the plant as such or in a modified form.

How far the effect of yeast on the crop is transmitted to animals was tested by the following experiment. By the courtesy of the Government Entomologist, Rao Sahib Y. Ramachandra Rao, two small plots each measuring 2 cents in area were laid out in his Insectary compound. Both the plots were manured with complete mineral manure and wheat was sown. One plot received a top dressing of 1½ pounds of wet yeast residues from a brewery. The usual initial depressing action of yeast was observed. Later on this wore off, the yeasted crop grew slightly better and the grain yield was 5·3 per cent. more than the non-yeasted plot. The grain from both the plots were submitted to Lieut.-Col. R. McCarrison who very kindly tested their nutritive values. With his kind permission the group results of two experiments on rats are given below.

1st Experiment.

Total body weights of groups of rats in grammes.

Treatment for plot	1st day	20th day	27th day	34th day	41st day	48th day	55th day
Mineral manure only	254	356	415	459	502	563	599
Mineral manure *plus* yeast	254	368	422	458	509	566	594
2nd Experiment.							
Mineral manure only	405	470	533	556	598	667	668
Mineral manure *plus* yeast	402	505	537	576	611	660	689

In the first experiment there was no difference ; in the second experiment there was a slight difference in favour of yeasted wheat but it is of no significance.

Judging from the differences in the early stages of the two experiments in favour of yeasted wheat the results may at best be interpreted to indicate that larger applications of yeast would likely yield a grain with better nutritive value. The experiments will be repeated with larger dressings of yeast.

Meanwhile, we may look in another direction for the information we want.

The results of experiments with plants and animals in parts 1 and 2 of this paper afford some evidence on the point at issue.

The seed from the farmyard manure plot had better cropping value than that from the no manure plot. Therefore, according to Bottomley's terminology, the "Auximonic" effect of " Cattle manure seed " was greater than that of the " No manure seed." Now, the results of feeding trials with pigeons and rats have shown that the same " Cattle manure seed " contained more " Vitamins " than the "No manure seed." That is, a seed which had a greater auximonic value as judged by vegetation tests also had a greater vitamin and nutritive value for animals. *Vice versâ* yeast which is known to contain vitamins for animals has been shown to have an auximonic effect on plants. It would, therefore, appear that auximones for plants and vitamins for animals are the same or, if different, exist together and are interdependent and function in different ways according to the organism into which they are introduced and the conditions under which they operate.

Based on this hypothesis, an explanation may be found for the differences in the nutritive values of the differently manured grains and for the similarity in the results of experiments with plants and animals.

It may be stated that in the case of the farmyard manure plot the decomposing organic matter supplied some very active constituent (Auximone) which vitalised the young crop in its initial stages and thus enabled the adult plants to manufacture "Vitamins" vigorously. The total quantity of " Vitamin " made up of the initial *plus* the subsequently produced " Vitamins " was enough to endow the grain from the farmyard manure plot with the highest nutritive value.

In the case of the mineral manure and no manure plots the lack of organic matter failed to supply the initial quantity of " Vitamins " and this circumstance probably also reduced the efficiency of the plant to manufacture " Vitamins." The net result was " Vitamin " deficiency in the grain from these plots.

Apart from the absorption of the active constituents from the organic *debris*, there is also the contribution of these by the micro-organisms in the soil.

In the light of our experiments with yeast something more than direct absorption by the plant of some vitalising constituent from organic matter would also appear to take place. It would appear that in the case of farmyard manure, as a result of bacterial decomposition of organic matter, the " Vitamins " are absorbed by the bacteria in addition to what they are capable of manufacturing for them-

selves. The bacteria die off after a time and the " Vitamins " present in them are absorbed by the plant and passed on to the animal.

The differences observed in the nutritive values between " Chemical manure grains " and " No manure grains " would seem to lend support to this view. In both these plots there was a lack of organic matter and so the bacteria had no initial supply of "Vitamins." But in the case of the mineral manure plot there was available plenty of mineral food and so the bacteria could multiply themselves in large numbers and manufacture " Vitamins " for themselves and pass on to the plant in a greater quantity than in the case of no manure plot but in a smaller quantity than in the case of the cattle manure plot where an initial supply of " Vitamins " was available. In the case of the no manure plot neither organic nor mineral matter were available and so the crop had not the benefit of an initial start and had to depend solely on the " Vitamins " manufactured by itself. Consequently, the amount of "Vitamins" available in this crop was low.

One more point requires to be explained and that is the different order of superiority for the differently manured *Ragi* and wheat. It will be remembered that both in the plant and animal experiments the order of superiority for millet was in the order " Cattle manure seed," " Mineral manure seed " and " No manure seed " and that for wheat the order was changed, " No manure wheat " occupying the second rank shifting the place of " Mineral manure wheat " to the last. This variation may be due to the nature of the crop. It may also be that in the no manure and mineral manure plots, as in the case of cattle manure plot, the direct and indirect effects of organic matter were operating but in opposite directions. For the direct effect there was inadequacy of organic matter to provide for the initial supply of vitamins : for the indirect effect there was again the inadequacy of organic matter to maintain the optimum moisture conditions necessary for the development of bacteria. But in the case of the mineral manure plot there was available plenty of mineral food and so the bacteria could multiply and manufacture "Vitamins" for themselves provided optimum moisture conditions were prevailing. If unfortunately for them moisture conditions were low, the position would be worse for them as well as for the plant than in the no manure plot, because the large amount of mineral matter in the soil would unduly concentrate the soil-solution and check the development and multiplication of the organisms and consequently the vitamins available to the plant would be even lower than in the case of no manure plot. This probably accounts for the lower nutritive and cropping values of " Mineral manure wheat " than that of " No manure wheat " in opposition to the results with millets.

It would thus appear that the micro-biological population of the soil has an important biological part to play in addition to their bio-chemical functions involved in the disintegration of organic matter and bringing it into a form suitable for the use of the plant.

From a consideration of the experimental results it would appear that the role of organic matter generally and of farmyard manure in particular is, in addition to the indirect physical and biochemical effects, the direct action of completing the vitamin cycle in the co-operative existence of animal and plant.

Summary of experimental results and conclusion.

The experimental evidence so far considered may now be summarised :—

(1) The effect of manuring a crop persisted in the seed and was visible in the next crop when the seed was sown in a soil of moderate fertility.

(2) A manured crop gave a seed with a better cropping value than an unmanured crop.

(3) A crop manured with cattle manure gave a seed with a better cropping value than that from a crop manured with mineral manure or not manured at all.

(4) A crop manured with mineral manure gave a seed with a better cropping value than that from an unmanured crop. But the superiority of "Mineral manure seed" over "No manure seed" varied with the nature of the crop.

(5) The results of animal nutrition experiments by Lieut.-Col. R. McCarrison with the same grains as those used in plant experiments show that the "Cattle manure seed" was more nutritious than "No manure seed" or "Mineral manure seed."

(6) The grain from a crop manured with mineral manure possessed better nutritive value than the grain from an unmanured crop. As in the case of experiments with plants the superiority of "Mineral manure seed" over "No manure seed" varied with the nature of the crop.

(7) Fermented farmyard manure was found to possess better manurial value than fresh farmyard manure.

(8) Synthetic farmyard manure prepared by fermenting grass and stubble had as good a manurial value as fermented natural farmyard manure.

(9) The water and alcoholic extracts of fermented farmyard manure and the residue were found to have almost equal manurial value.

(10) The water extract of fresh farmyard manure was superior in its manurial value to the residue, but the manurial value of the water extract of fresh farmyard manure was distinctly inferior to the water extract from fermented farmyard manure.

(11) A small quantity of yeast stimulated a crop and in comparison with fermented farmyard manure gave nearly one and a half times the yield.

(12) A minute amount of yeast stimulated to a marked extent the growth of crop even after the nitrogen and phosphoric acid content of the yeast were compensated for by the addition of inorganic nitrogen and phosphoric acid.

(13) Evidence and arguments are advanced to show that organic manures besides improving the physical condition of the soil and being sources of ordinary food for plants also supply some agents like "Auximones" or "Vitamins" which contribute greatly to the growth and reproduction of the plant and through the plant and its seed supply more food to animals and plants.

(14) Evidence and arguments are advanced to show that in addition to their bio-chemical activity the micro-biological population of the soil contribute directly to the plant some stimulant which is ultimately passed on to the animal.

(15) The similarity in the results of plant and animal experiments would point to the direction that Bottomley's "Auximones" for plants and "Vitamins" for animals are probably the same, or if different, exist together and are interdependent, functioning in different ways according to the organism in which they are introduced and the conditions under which they operate.

The results are of great interest and importance and if confirmed generally in other places would be of far reaching value. The mutual support and corroboration that exists between the independently conducted experiments with plants and animals lend strong support to the view that manuring alters the character of the seed. It may be that in the instances considered the results were of an accentuated character as the seed experimented with came from plots that had been under intensive cultivation for a number of years and where the differential manurial effect was of an emphasised nature.

It may also be that in a soil with a good supply of organic matter or with silt brought down by rivers flowing through forest areas, the disparity in the cropping capacity and the nutritive value of the seed from differently manured crops may not be as evident as in the present instance or may entirely disappear.

Nevertheless, the results direct pointed attention to certain fundamental aspects of the problem of manuring and plant nutrition.

Apart from their scientific interest, the findings of the investigations are of immediate practical value to South Indian Agriculture.

It is clearly shown that a crop should be manured—

firstly—to obtain increased yields,

secondly—to obtain a seed with a good cropping capacity in its next generation, and

thirdly—to obtain a crop with high nutritive value.

The importance of organic manures is emphasised and the lines of future manurial programme are clearly shown.

For purposes of manuring a crop, artificials alone are inadequate. The best results all round are obtained by a judicious combination of organic and artificial manures.

It is further shown that manuring is one of the ways by which crop improvement can be effected, or the quality of a strain may be prevented from rapid deterioration.

The experimental evidence emphasises the importance of organic manures to South Indian soils which are very deficient in organic matter and indicate in no unmistakable terms the manurial policy to be followed in the future. A basal dressing of a bulky organic manure, supplemented where necessary by artificial manures or a judicious combination of both in which the organic manure preponderates seems to be the best system of manuring.

The inadequacy of the available farmyard manure and other organic manures to meet the needs of the arable area is well known. This being so, the situation calls for immediate action in husbanding our resources of organic manures by :—

(1) the prohibition or restriction of export of oil seeds, cakes and bones,
(2) the utilization of all waste organic materials for manurial purposes,
(3) the utilization of sewage by the activated sludge process,
(4) the utilization of night soil by poudrette manufacture or trenching.

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EXPERIMENTS ON THE FEEDING OF *SORGHUM* SILAGE AND CONCENTRATE TO SCINDI CALVES.

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Object.

These experiments were undertaken to determine the consumption and digestion of rations by Scindi calves and to estimate the productive values of the rations employed.

Procedure.

The concentrate mixtures used in the experiment, the rates of feeding and other relevant data are given in Table I.

TABLE I.

Concentrates employed in the experiment.

Concentrate	Composition	% of Protein	*Amount fed lb.	*Net energy of concentrate fed
A.	Wheat bran	13	1·6	1·0
B.	Wheat bran, 2 parts; Groundnut cake, 1 part	26	1·3	1·0
C.	Broken rice, 1 part; Groundnut cake, 1 part	31	·9	·8

* Per 100 lb. live weight.

These concentrates were selected in order to observe the relative effects of bulk net energy and protein content upon consumption, digestion and growth. There was considerable difficulty in obtaining a sufficient number of weaned calves. It was quite impossible to get enough for a simultaneous trial. We therefore took six calves at a time and put two on each of the above concentrates. At intervals of about six weeks fresh batches of calves became available. Three batches were tested in this way. As the calves were far from uniform in size and age, it was decided to feed the concentrate as accurately as possible in proportion to live weight. Calves on A ration, for example, were fed at the rate of 1·6 lb. per 100 lb. live weight. This ration became almost excessive when the animals increased considerably in weight. In a few cases, the ration had to be reduced slightly on this account. The rations were generally increased once a fortnight in accordance with the increase in live weight. *Sorghum* silage was used as roughage. It was fed *ad lib.* and the amount consumed by each animal was determined daily. Live weights were taken daily except while digestion experiments were in progress. From the daily records weekly averages for concentrate consumption, roughage consumption, and live weight for each animal were found. These experimental results are given in full in the Appendix. In the course of the feeding trials, five sets of digestion experiments were carried out. The first two batches of calves were given a mineral supplement of lime. The third batch did not receive this supplement. The results of these experiments will be discussed under the following heads :—

1. Food consumption.
2. Live weight increases.
3. Digestion experiments.
4. Nitrogen and mineral balances.

Food consumption.

The procedure employed in feeding has been described above. The results of the full data relating to food consumption (Table I Appendix) are summarised in the accompanying Table (No. II) in which also the average live weight of each animal is shown.

TABLE II.

Daily average food consumption in lb. dry matter.

—	Concentrate A		Concentrate B		Concentrate C	
Calf No.	1	2	3	4	5	6
1st Batch, averages for 84 days—						
Roughage	2·352	2·310	2·703	2·631	3·128	2·672
Concentrate	3·869	2·913	2·879	2·334	2·084	1·289
TOTAL	6·221	5·223	5·582	4·965	5·212	3·961
Average live weight	243	178	220	185	234	166

Daily average food consumption in lb. dry matter—contd.

—		Concentrate A		Concentrate B		Concentrate C	
2nd Batch, averages for 96 days—	Calf No.	7	8	9	10	11	12
Roughage		2·351	2·268	3·433	2·459	3·548	2·798
Concentrate		3·525	3·824	3·620	2·515	2·301	1·579
	TOTAL	5·876	6·092	7·053	4·974	5·849	4·377
Average live weight		216	234	275	188	254	176
3rd Batch, averages for 98 days—	Calf No.	13		15	16	17	18
Roughage		2·090		2·704	2·070	2·963	2·769
Concentrate		3·854		3·237	2·009	1·996	1·638
	TOTAL	5·944		5·941	4·079	4·959	4·407
Average live weight		222		240	152	215	177

Consumption of concentrate.

As it was intended to feed the concentrate in proportion to live weight, the actual consumption should show a regularity when plotted in graphic form. The accompanying chart No. I shows the relation between concentrate consumption and live weight. It will be noted that very fair regularity was maintained in the feeding. One animal No. 14 was a "bad doer," did not eat well and made very poor progress. It has been omitted from this and the succeeding charts.

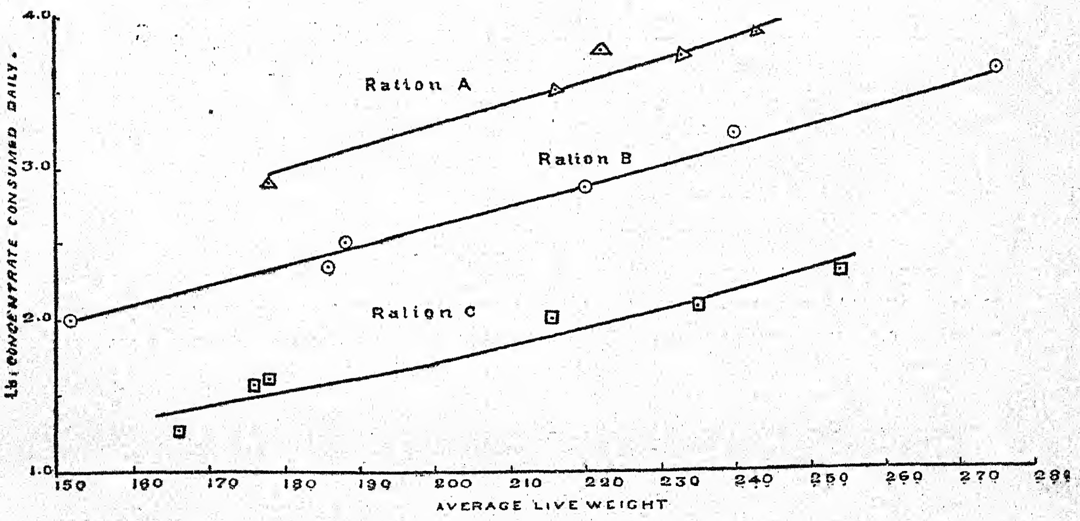

CHART NO. I.
Concentrate consumption.

Consumption of roughage.

Chart No. II shows the relation between live weight and roughage consumption. It has to be recollected that the roughage was fed *ad lib.* The figures in this chart are, therefore, a measure of the amount which the animals chose to eat. The chart brings out the following points :—

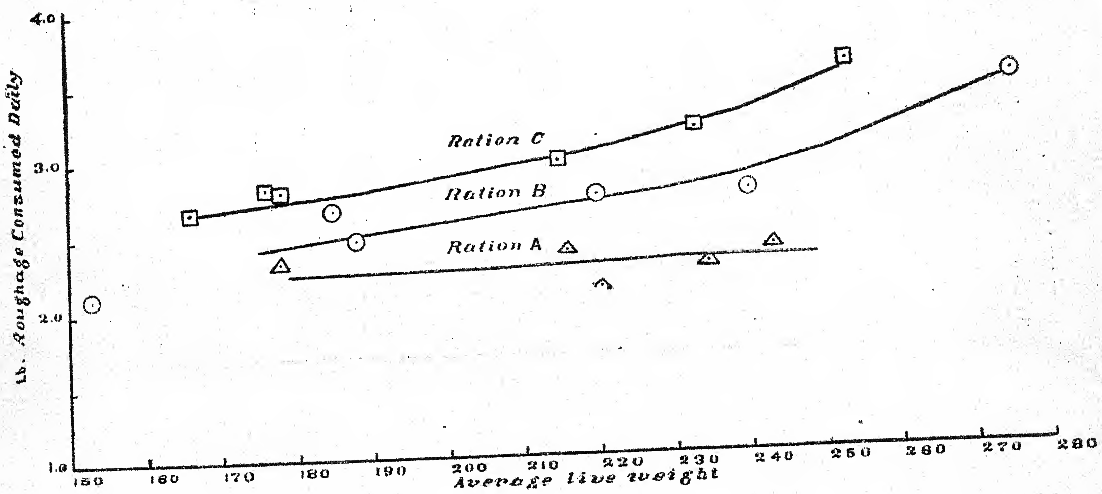

CHART No. II.
Roughage consumption.

1. There is a remarkable regularity in the consumption of roughage.
2. The roughage consumption is very closely related to the type of concentrate feeding practised. Three distinct lines of roughage consumption are obtained for the three types of concentrate feeding.
3. With rations B and C, there is a regular increase in roughage consumption with increasing live weight. With ration A, the consumption of roughage hardly increases at all.

A comparison of charts I and II shows that a high rate of concentrate feeding results in low consumption of roughage and *vice versâ*. In chart I, the A line is on top and the C line at the bottom. In chart II, the positions of these lines are reversed.

Consumption of total dry matter.

Chart No. III shows the relationship between total food consumption and live weight. In this chart the points already noted above have to be observed again. There is once more a remarkable regularity in the amount of total dry matter consumed and the regularity is closely related to the nature of the concentrate fed.

Three distinct lines of total dry matter consumption are obtained corresponding to the three types of concentrate fe ding and with each type of ration the total consumption increases regularly with increasing live weight. We observe in this chart, further, that the total consumption is greatest with ration A and least with ration C. Taking the three charts together, we find there is a tendency for concentrate

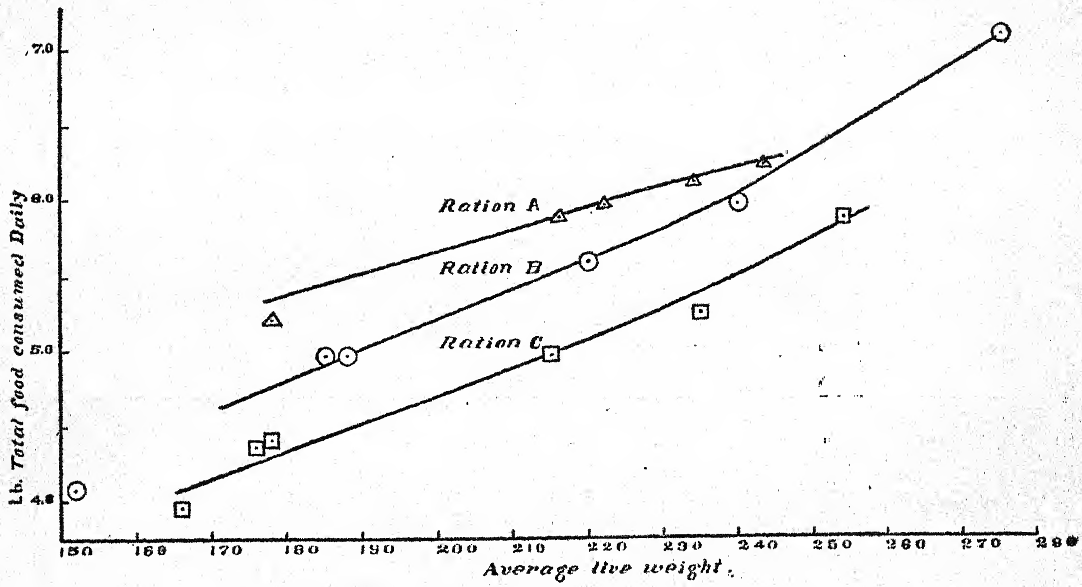

CHART No. III
Total food consumption.

and roughage consumption to balance one another, but the balancing effect is not complete. A deficiency of concentrate is not quite compensated by the increase in roughage. The calves receiving least concentrate consumed least total dry matter and the animals which were fed the highest allowance of concentrate consumed most food. Chart III shows, however, that the last statement only holds good up to a certain point beyond which graphs A and B merge into one another. The merging of the graphs shows that at this stage the animals have developed a greater capacity for roughage and can make a full meal with a reduced allowance of concentrate. This is a point of practical importance.

We have to consider now the actual data relating to food consumption. The most reliable figure which can be derived from chart III is the one referring to the animal of average live weight, *i.e.*, about 210 lb. We find that our 210 lb. calves on rations A, B and C respectively consumed 5·7, 5·5 and 4·93 lb. per head or 27·1, 26·2 and 23·5 lb. per 1000 lb. live weight. The Wolff Lehmann standard for calves

weighing 210 lb. allows 24 to 25 lb. per 1000 lb. live weight. Our calves on rations A and B, therefore, consumed more than the accepted standard, whilst the calves on C ration came fairly near the Standard. Seeing that the breed of animals used in our experiments has not been selected for high consumption capacity, the result must be considered exceptionally favourable. We attribute this good consumption entirely to the quality of the roughage used by us. Well-made *Sorghum* silage seems to be a very good fodder for calves. It is eaten with relish and the animals never get tired of it.

Live weights.

The weekly average live weights of all the animals are shown in Table II Appendix. These figures are summarized in the accompanying Table III.

TABLE III.

Increase in live weights.

	Ration A		Ration B		Ration C	
Calf No. .	1	2	3	4	5	6
1st Batch—						
Average live weight 12th week . . .	296·0	220·4	265·8	227·0	276·0	195·8
,, ,, ,, 1st week . . .	190·4	134·9	174·0	142·9	191·6	137·1
Increase in 11 weeks	105·6	85·5	91·8	84·1	84·4	58·7
,, per day	1·371	1·110	1·182	1·092	1·096	0·762
Average live weight for whole period . .	243·2	177·6	219·9	184·9	233·8	166·4
Calf No. .	7	8	9	10	11	12
2nd Batch—						
Average live weight 14th week . . .	268·4	293·0	335·1	236·3	298·3	210·7
,, ,, ,, 1st week . . .	162·6	174·9	214·6	140·0	209·1	140·3
Increase in 13 weeks	105·8	118·1	120·5	96·3	89·2	70·4
,, per day	1·163	1·298	1·324	1·058	0·980	0·773
Average live weight for whole period . .	215·5	233·9	174·8	188·1	153·7	175·5
Calf No. .	13	14	15	16	17	18
3rd Batch—						
Average live weight 14th week . . .	256·0	221·0	290·0	180·0	342·0	204·0
,, ,, ,, 1st week . . .	187·0	144·0	190·0	118·0	187·0	143·0
Increase in 13 weeks	69·0	77·0	100·0	68·0	55·0	55·0
,, per day	0·758	0·846	1·099	0·747	0·604	0·604
Average live weight for whole period . .	221·5	187·5	240·0	152·0	214·5	176·5

The daily live weight increase is calculated from the initial and final weekly averages. The results for the 1st and 2nd batches are shown in chart IV. Admitting the paucity and other shortcomings of the data, the chart nevertheless brings out the following points :—

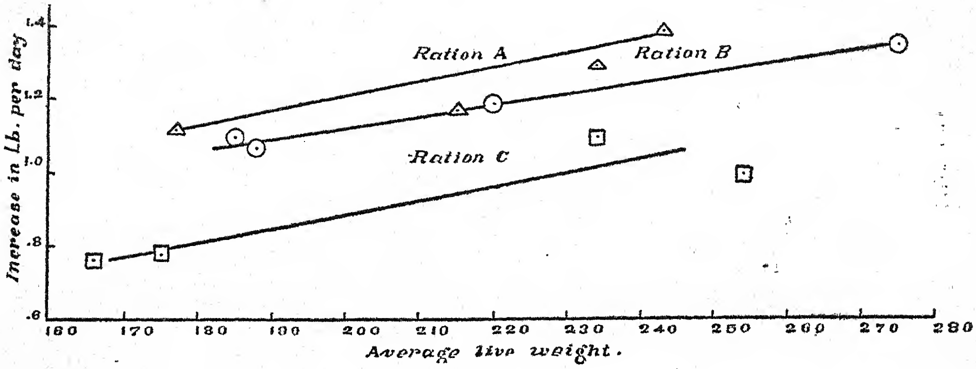

CHART NO. IV.
Live weight increase of calves.

(*a*) The larger animals tend to grow more rapidly than the smaller ones. It may be concluded that this will be the result generally when concentrate is fed in proportion to live weight. It should be noted, however, that with rations B and C the roughage consumption increased quite as rapidly as the concentrate. It would appear, therefore, that animals at this stage naturally tend to accelerate their rate of growth.

(*b*) The live weight increase depends upon the nature of the ration. The results with ration C are decidedly the lowest, and, on the whole, ration A produced somewhat greater growth than ration B.

(*c*) Generally, a remarkably high rate of increase was obtained. Only three animals increased less than a pound a day and these three were on ration C. All the animals on rations A and B increased more than a pound a day.

There is no doubt about the high rate of increase, but it varies according to the live weight as already pointed out, hence we can only specify a rate of increase for a definite live weight. The best procedure is to calculate the mean rate of increase and apply it to the average live weight. In this way, we find that 210 lb. animals on rations A, B and C increase by 1·24, 1·16 and ·90 lb. a day respectively. The same result could be read off from the chart. Without laying stress on these figures they give a fair representation of the live weight increases found. Turning back for a moment to the food consumption data, it will be seen that the same

210 lb. animals consumed 5·7, 5·50 and 4·93 lb. dry matter respectively. Without further information this food seems inadequate for producing such growth.

The third batch of calves has to be considered next. Chart V shows the three lines which roughly represent the growth of the first and 2nd batches. The results

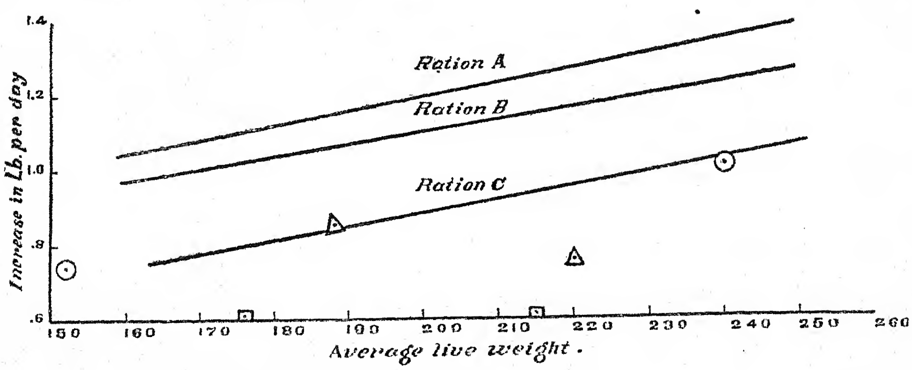

CHART No. V.
Live weight increase of 3rd batch.

obtained with the third batch are indicated by the experimental points. It is clear from this chart that the third batch is very far behind the others in growth. There are two circumstances connected with this batch requiring notice. In the first place, there is some doubt about the quality of the silage they received. This point is considered under the digestion experiments. We are not inclined to attribute the failure to the silage. Secondly, it will be recollected that the first and second batches received a lime supplement which was not given to the third batch. It seems natural therefore to attribute the failure to a lack of lime. Lime balance experiments which will be described later hardly support this view. We have to conclude in the case of these calves that there was an undoubted failure to grow rapidly, but there is no clear evidence to show that the failure was due to a shortage of lime. The test has been inconclusive.

Digestion experiments.

1. *Digestibility of the mixed ration.* Digestion experiments were carried out with the first batch of animals once, with the second and third batches twice. One of the latter tests was carried out simultaneously with the two groups. We have, therefore, digestion data referring to four silage samples and each silage sample was fed with three different types of concentrate. The digestion of the total organic matter (including concentrate and roughage) as found in these tests is shown together with other significant data in the accompanying Table.

Table IV.

Digestion of mixed rations.

Calf No.	Ratio of roughage to concentrate	Total of organic matter consumed	Amount of organic matter digested	% Digested organic matter.	Silage
		grm.	grm.		
Ration A.—					
1	·739	2547	1621	63·66	No. 1.
2	·898	2148	1304	60·74	
7	·748	2743	1824	66·51	No. 2.
8	·717	2804	1901	65·93	
7	·729	3042	2057	67·60	No. 3.
8	·665	3205	2103	65·61	
13	·758	2506	1718	68·53	
14	·812	2025	1343	66·34	
13	·537	2614	1639	62·69	No. 4.
14	·560	2054	1296	63·08	
Ration B.—					
3	1·071	2257	1366	60·51	No. 1.
4	1·359	2019	1326	65·69	
9	·895	3103	2112	68·07	No. 2.
10	1·051	2348	1575	67·05	
9	·985	3599	2514	69·86	No. 3.
10	1·011	2591	1798	69·39	
15	1·060	2513	1711	68·09	
16	1·299	1735	1191	68·66	
15	·798	2531	1691	66·79	No. 4.
16	1·067	1777	1076	60·55	

Digestion of mixed rations—contd.

Calf No.	Ratio of roughage to concentrate	Total of organic matter consumed	Amount of organic matter digested.	% Digested organic matter	Silage
		grm.	grm.		
Ration C.—					
5	1·453	2053	1257	61·21	No. 1.
6	2·227	1555	998	64·16	
11	1·760	2869	1875	65·33	No. 2.
12	1·902	2104	1372	65·93	
11	1·549	2939	2108	68·60	No. 3.
12	1·759	2193	1511	66·88	
17	1·849	2318	1575	67·94	
18	2·055	1985	1325	66·67	
17	1·276	2064	1322	64·08	No. 4.
18	1·603	1920	1151	59·95	

Before examining these figures, it has to be noted that the concentrates remained practically uniform in quality throughout the series of tests. Any differences in the digestibility of the entire ration must be attributed, therefore, to variations in the quality of the silage. Considering first the results obtained with concentrate A, the best digestion of organic matter appears to have occurred when silage No. 3 was fed. Silage No. 2 shows a digestion which is only slightly lower than No. 3. The average results of silages 1 and 4 are about equal and distinctly lower than silages 3 and 2. Looking at the ratios of roughage to concentrate, it appears that the appetites of the animals eating silage No. 4 were below the average. Referring now to the results with concentrates B and C, it will be noticed that they run parallel to the digestion figures obtained with concentrate A. The three sets of results corroborate one another satisfactorily. It has to be noted, however, that there are considerable divergences between several of the duplicate determinations. In the case of calves 1 and 2 on silage No. 1, calves 15 and 16 on silage No. 4 and calves 17 and 18 on silage No. 4, we might attribute the divergences to the proportion of roughage in the food actually consumed, but this explanation does not hold good for calves 3 and 4 on silage No. 1 and for calves 5 and 6 on silage No. 1. In the latter instances, the efficiency of digestion by the individual is the significant variant and it seems likely that the same factor is the main cause of divergences in other cases too. Further, the results with calves 13 and 14, 15 and 16, 17 and 18 show that the relative efficiency is liable to vary appreciably from time to time in an

irregular manner. The data are not sufficient to enable us to deal with these divergences statistically, but there are the following facts to go on :—

Silages 1, 2 and 4 were each tested with six different animals. Silage No. 3 was tested with 12 animals. In no single instance was the digestion of silage No. 1 or silage No. 4 as good as the digestion of silages 3 and 2. Looking at the six results with silage No. 2 and the 12 results with silage No. 3, we find only one case in which No. 2 gives a better result than No. 3.

From this discussion we feel justified in concluding that the figures show us the true order of digestibility of these four silage samples. The outstanding fact in these figures is the very high digestion attained in all the tests. In the numerous calf feeding experiments carried out by the Nutrition Section, no digestion figures to approach these results have been met with. There is no doubt that *Sorghum* silage is exceptionally well digested by calves. It has to be remembered too that this high digestion was maintained in spite of heavy consumption.

Productive values of the rations.

From the digestion results of Table IV and using the Bangalore graphic method for estimating net energy values, we find the net energy value of the rations to be approximately ·58 Therm per lb. of dry matter. Using this figure the following results are obtained for the productive values of the rations consumed by 210 lb. calves.

TABLE V.

Productive values of rations consumed by 210 lb. calves.

	Ration A	Ration B	Ration C
Dry matter consumed per day, lb.	5·70	5·50	4·93
Net energy of ration, Therms	3·30	3·19	2·86
Net energy for maintenance, Therms . . .	2·10	2·10	2·10
Balance for growth, Therms	1·20	1·09	·76
Average daily live weight increase, lb. . . .	1·24	1·16	·90
Net energy per lb. increase, Therms . . .	·97	·94	·85

The figures are as good as could be expected from the previous experimental results. One Therm is probably a fair allowance for the energy value of the gains made by these young calves. We feel, therefore, that the high gains recorded under the section dealing with live weights are accounted for reasonably well by the high digestibility of the ration.

2. *Digestibility of silage.* The figures in Table V give the digestion of the entire ration. The digestibility of the silage may be estimated from the results obtained with ration C. For the computation the following digestion coefficients have been assumed :

	Fibre	Nitrogen free extract
Cake	10%	60%
Rice	100%	90%

Working with these coefficients the silage samples are found to have the digestibility shown in Table VI.

TABLE VI.

Computed digestibility of silage.

Silage No.	Calf No.	% Digestion of carbohydrate		% Digestion of organic matter	
		Individual	Average	Individual	Average
1	5	50·28	53·99	48·77	52·12
	6	57·70		55·51	
2	11	58·91	59·23	56·44	56·69
	12	59·51		56·94	
3	11	63·54	63·99	60·82	61·22
	12	65·03		62·19	
	17	64·32		61·50	
	18	63·04		60·36	
4	17	54·23	51·72	52·16	50·04
	18	49·50		47·91	

The deviations in the duplicates of samples 1 and 4 are so serious that the averages have little significance. From the more extensive figures of Table V we see that silages 1 and 4 are about equally digestible. We may therefore take 51, the average of the 4 figures for these samples in Table VI, as a fair estimate of the digestibility of samples 1 and 4. It may be concluded, accordingly, that the calves digested about 51%, 57%, 61% and 51% of the organic matter of these four samples of silage. It remains now to see whether these differences in digestibility are related to differences in chemical composition. The compositions of the four silages are shown in Table VII.

TABLE VII.

Chemical composition of four silage samples.

Silage No.	Crude protein	Ash	Silica in ash	Ether extract	Fibre	Nitrogen free extract	Ratio N. F. E. to fibre	% digestion of organic matter
1 . .	5·52	10·11	5·20	2·56	36·97	44·86	1·213	51
2 . .	7·31	8·64	4·07	1·64	33·09	49·31	1·490	57
3 . .	5·89	12·46	6·57	2·09	30·16	49·40	1·638	61
4 . .	6·60	14·98	8·76	1·75	33·95	42·66	1·256	51

These figures show that the digestibility is roughly proportional to the ratio between fibre and nitrogen free extract. The digestibility increases as the proportion of fibrous carbohydrate decreases. The general quality of the silage fed during the entire test may be gauged now by this criterion. Three composite analyses were carried out. The periods covered by the composite samples and by the feeding tests were as follows :—

	Feeding tests	Composite samples
1st test .	23rd May to 15th August.	23rd May to 11th September.
2nd test .	28th July to 3rd October.	2nd September to 17th October.
3rd test .	22nd September to 28th November.	18th October to 5th December.

The first sample covers the entire first test, the major part of the second test and the commencement of the third test. The second sample covers the latter part of the second test and the major part of the third test. The last sample covers the remaining six weeks of the third test and extends beyond it somewhat. The analytical figures for the three samples are given in Table VIII.

TABLE VIII.

Chemical analysis of composite silage.

	1st sample	2nd sample	3rd sample
Crude protein	5·00	5·69	6·31
Ash	10·14	12·91	19·33
Ether extract	1·70	2·01	2·26
Fibre	36·30	33·43	29·23
Nitrogen free extract	46·36	45·96	42·82

The third sample is peculiar in its high ash content, but the digestion results in Table VII showed no relationship between ash content and digestibility. The ratio of fibre to nitrogen free extract was found to be the governing factor and in this respect the third sample is satisfactory. The silage consumed by the third batch of calves during the last six weeks of the test was certainly high in ash content, but as far as we can judge it was easily digestible. Further, for the greater part of the test the third batch received what has been definitely proved to have been the very best silage. It does not seem probable, therefore, that the failure of the third batch can be attributed to the quality of the silage.

3. *The digestion of crude protein or total nitrogen.* The digestion of crude protein has to be considered in exactly the same way as the total organic matter. We have to take into account four silage samples each fed with three different concentrates. The results obtained are shown in Table IX.

TABLE IX.

The digestion of crude protein nitrogen in grm. per day.

	Concentrate A		Concentrate B		Concentrate C	
Calf No. .	1	2	3	4	5	6
Nitrogen in roughage	10·64	10·00	11·46	11·43	11·95	10·55
Nitrogen in concentrate	34·25	26·47	52·35	41·10	49·20	28·66
Total nitrogen in ration	44·89	36·47	63·81	52·53	61·15	39·21
Nitrogen digested	27·33	21·08	44·70	37·93	40·07	26·25
% Digestion	60·88	57·80	70·05	72·21	65·53	66·95
Calf No. .	7	8	9	10	11	12
Nitrogen in roughage	15·03	15·42	18·76	15·40	23·43	17·65
Nitrogen in concentrate	38·39	41·08	76·29	53·29	54·71	38·12
Total nitrogen in ration	53·42	56·50	95·05	68·69	78·14	55·77
Nitrogen digested	32·88	34·22	67·33	49·36	51·84	36·01
% Digestion	61·55	60·57	70·84	71·86	66·34	64·57

The digestion of crude protein nitrogen in grm. per day—contd.

	Concentrate A		Concentrate B		Concentrate C	
Calf No. .	7	8	9	10	11	12
Nitrogen in roughage	13·66	13·62	19·23	13·88	19·01	14·89
Nitrogen in concentrate	41·56	45·50	82·78	58·72	57·84	39·87
Total nitrogen in ration	55·12	59·12	102·01	72·60	76·85	54·76
Nitrogen digested	32·10	33·55	74·49	52·23	50·92	35·10
% Digestion	58·13	56·75	73·02	71·94	66·26	63·92
Calf No. .	13	14	15	16	17	18
Nitrogen in roughage	11·50	9·67	13·93	10·57	16·13	14·23
Nitrogen in concentrate	33·68	26·39	55·62	34·39	40·75	32·21
Total nitrogen in ration	45·18	36·06	69·55	44·96	56·88	46·44
Nitrogen digested	25·32	19·90	48·74	30·31	35·63	27·43
% Digestion	56·04	55·19	70·08	67·42	62·64	59·07
Calf No. .	13	14	15	16	17	18
Nitrogen in roughage	11·45	9·24	14·09	11·50	14·51	14·82
Nitrogen in concentrate	37·39	28·98	61·98	37·85	45·47	36·99
Total nitrogen in ration	48·84	38·20	76·07	49·35	59·98	51·81
Nitrogen digested	27·91	21·75	53·59	34·16	39·22	31·97
% Digestion	57·14	56·94	70·45	69·22	65·39	61·71

Before examining these figures, it has to be understood that we are dealing with three levels of protein feeding. In each column the concentrate (or concentrate nitrogen) was fed in proportion to the live weight, but the level of feeding was not the same in the three columns. The animals under A received least and under B most protein per 100 lb. live weight. The figures in Table IX are unavoidably complicated on account of the great range in live weight, but one fact can be discerned from the data as they stand. It is clear that the percentage digestion of nitrogen was invariably highest with ration B and lowest with ration A. The point is much more evident if we take the averages of all the results under each column. The figures given in Table X have been obtained in this way.

TABLE X.

Average digestibility of crude protein nitrogen.

Average of ten tests	Ration A	Ration B	Ration C
Live weight of animal	212·8	211·5	204·5
Consumption of crude protein nitrogen grams per day.	47·32	69·41	58·09
Nitrogen content of faeces, grams per day.	19·83	20·34	20·78
Crude protein nitrogen digested, grm. per day.	27·49	49·12	37·78
% Digestion	58·10	70·71	64·22

It is interesting to notice that the nitrogen voided in the faeces is practically identical for the three groups. No significance has been found in this fact. It appears to be a mere coincidence. On the other hand, the proportion of nitrogen in the ration and the resulting digestibility is significant. With an increase of nitrogen in the ration, the digestibility increases rapidly and the figures obtained are to be relied on, because each is the average of ten fairly concordant results. These digestion results cannot be explained satisfactorily by the assumption of fixed digestion coefficients and definite losses of metabolic nitrogen. It appears that the digestion of nitrogen is definitely related to the proportion of nitrogen in the ration.

Nitrogen excretion in faeces.

For the nitrogen excretion in the faeces we have another set of figures, namely, the percentage of nitrogen in the fresh faeces calculated on the dry basis. The figures are given in full in Table XI.

TABLE XI.

Nitrogen content of fresh faeces calculated on the dry basis.

Silage	Ration A % Nitrogen in faeces		Ration B % Nitrogen in faeces		Ration C % Nitrogen in faeces	
1 . . .	1·585	1·540	1·786	1·751	2·231	1·933
2 . . .	1·935	1·935	2·388	2·135	2·289	2·351
3 . . .	1·906	1·920	2·061	2·052	2·271	2·364
	2·019	1·925	2·106	2·166	2·356	2·376
4 . . .	1·698	1·712	2·062	1·821	2·188	2·057
Average . .	1·818		2·033		2·241	

In every line the figures in the first column are lowest and in the last column highest. Out of the 30 figures in this Table there is only one irregular result. It may be accepted as an established fact, therefore, that the average nitrogen contents of faeces from rations A, B and C are 1·818, 2·033 and 2·241% respectively. These figures can only be correlated with the amounts of roughage or roughage nitrogen eaten by the three groups. The figures are shown in Table XII.

TABLE XII.

Relation between faecal nitrogen and roughage consumption.

—	Ration A	Ration B	Ration C
Average roughage consumption in grams dry matter per day.	1201	1402	1561
Average nitrogen content of roughage grm.	12·09	14·12	15·72
Average nitrogen content of faeces. (%).	1·818	2·033	2·241

It is clear from these figures that either the bulk of the roughage or the nitrogen in the roughage influences the nitrogen content of the faeces. To decide between these two alternatives, the results for each of the four silages must be considered separately. The figures are shown in Table XIII.

TABLE XIII.

Effect of different silage samples upon fæcal nitrogen content.

	Silage 1	Silage 2	Silage 3	Silage 4
Average roughage consumption in grams .	1182	1341	1586	1246
Average nitrogen content of roughage grm. .	11·00	17·61	14·19	12·60
Average nitrogen content of fæces . .	1·804	2·172	2·127	1·922

It appears from these figures that the fæcal nitrogen is most closely related to the amount of nitrogen in the silage. We conclude, therefore, that it is not so much the metabolic nitrogen associated with roughage consumption but the relatively indigestible nature of the silage nitrogen that affects the nitrogen content of the fæces.

Mineral balances.

The assimilation of lime and P_2O_5 was studied during the five digestion experiments. We have, therefore, one set of figures for the first batch of calves and two sets for each of the second and third batches.

Assimilation of phosphoric acid. Table XIV shows the total P_2O_5 in the ration and the amount assimilated in each test.

TABLE XIV.

Assimilation of P_2O_5 in gram per day.

Ration A			Ration B			Ration C		
Calf No.	P_2O_5 in Ration	P_2O_5 assimilated	Calf No.	P_2O_5 in Ration	P_2O_5 assimilated	Calf No.	P_2O_5 in Ration	P_2O_5 assimilated
1	39·07	5·79	3	28·03	5·52	5	15·69	4·15
2	31·45	3·80	4	23·66	4·97	6	11·61	3·52
7	41·25	9·09	9	39·81	9·42	11	18·73	6·69
7	59·53	20·16	9	52·32	18·43	11	18·42	5·81
8	44·42	10·02	10	28·70	8·98	12	13·56	5·85
8	64·58	21·43	10	37·37	13·61	12	13·47	5·34
13	48·44	13·55	15	35·72	9·75	17	15·37	5·84
13	43·11	10·32	15	32·77	9·46	17	13·63	4·76
14	38·24	12·76	16	22·96	7·63	18	11·87	3·55
14	33·13	8·13	16	21·06	7·53	18	12·05	4·05
AVERAGE	44·32	11·51	(AVERAGE)	32·24	9·53	(AVERAGE)	14·44	4·95

The means of such divergent figures have no significance as an average, but the last line of the table shows very definitely that the animals on ration C received least P_2O_5 and also assimilated much less than groups A and B. An examination of the individual results shows that there is a close correlation between the amount of P_2O_5 in the ration and the amount assimilated. It would appear from these results that the animals were in a condition to assimilate considerable quantities of P_2O_5 and the assimilation was generally limited by the amount present in the ration. It will be observed that C group which made the lowest growth received least P_2O_5, but this group also ate least food. The failure to grow rapidly cannot be attributed, therefore, to lack of P_2O_5. It is, however, possible that shortage of P_2O_5 may have been a contributory cause. This point will deserve attention in future work.

Assimilation of lime. Before examining the lime data, it is necessary to explain that the two tests with the second and third batches were carried out near the

commencement and near the end of the feeding trial respectively. The single test with the first batch was made near the end of that feeding test. The results for lime assimilation are given in Table XV and are grouped under early and late tests.

TABLE XV.

Assimilation of lime in grams per day.

	Ration A		Ration B		Ration C	
	Early	Late	Early	Late	Early	Late
Lime Supplement—						
Calf No.	1	1	3	3	5	5
CaO in ration	..	19·36	..	18·66	..	17·64
CaO assimilated	..	7·08	..	6·04	..	5·61
Calf No.	2	2	4	4	6	6
CaO in ration	..	17·39	..	18·06	..	16·10
CaO assimilated	..	5·73	..	6·42	..	5·30
Calf No.	7	7	9	9	11	11
CaO in ration	19·56	23·45	21·33	26·73	21·02	22·25
CaO assimilated	13·63	8·69	11·30	8·05	8·34	6·39
Calf No.	8	8	10	10	12	12
CaO in ration	20·06	24·03	18·39	21·36	17·66	18·95
CaO assimilated	11·84	8·89	11·30	8·05	8·34	6·39
No Supplement—						
Calf No.	13	13	15	15	17	17
CaO in ration	13·05	12·99	13·37	14·15	13·96	12·05
CaO assimilated	11·49	4·51	11·17	8·18	10·17	4·88
Calf No.	14	14	16	16	18	18
CaO in ration	10·66	10·33	9·65	10·77	10·57	11·99
CaO assimilated	10·02	5·30	8·32	6·17	7·12	5·44
Average—						
CaO in ration	15·83	17·93	15·68	18·29	15·80	16·49
CaO assimilated	11·74	6·70	10·46	7·65	9·28	5·81

The lime assimilation was found to have no relationship whatever to the amount of lime in the ration or to the amount of P_2O_5 assimilated, but it was observed that where two tests were made on the same animal the first test showed higher assimilation than the second. This is the only regularity that could be found

in the data for lime assimilation. Table XV shows that, without a single exception, less lime was assimilated in the late tests, and in the case of the first batch of calves, for which we have only late tests, the assimilation was low. Here it should be pointed out that the feeding experiments with the three batches were not commenced simultaneously. The course of feeding of the second batch was half finished when the third batch was introduced. Thus it happens that the late test with the second batch was actually carried out at the same time as the early test with the third batch. The difference found between early and late tests, therefore, cannot be due to any temporary unperceived peculiarity in the food or to climatic conditions. It is a real difference. The last two lines of the table bring out the difference clearly. The amount of lime in the ration remained constant, but the assimilation fell off appreciably. We are inclined to interpret this result as showing that in our rationing procedure lime assimilation was high in the early stages and fell off later when enough had been assimilated. The phenomenon, however, deserves to be studied further. Comparing the results obtained with and without lime supplements it cannot be said that the calves without the supplement failed to assimilate lime during the early stages of feeding. The percentage assimilation is, however, remarkable and the fæces of these calves during the early stage of the feeding were extraordinarily low in lime. This fact might have been expected to cause liquidity in the fæces but there was no untoward effect visible. The experiment seems to show that the animals were not short of lime—a conclusion which receives support from the fact that, like the individuals of the other batches, they reduced their assimilation towards the end of the test. It is possible, however, that we were on the border line of lime sufficiency and that there was after all a slight shortage, the only evidence for which is the failure to grow at the great speed attained by the first and second batches. According to Kellner a growing calf should assimilate about 14 grams of CaO per day. During the early part of the feeding, our calves came near this figure, but at later stages they fell far below it. In spite of that, the first and second groups grew steadily and rapidly and were in very fine condition at the end of the test. It is not likely that they were suffering from any shortage.

The percentages of lime and P_2O_5 in the rations actually consumed by our calves are given in the next Table XVI.

TABLE XVI.

Percentage of lime and P_2O_5 in rations.

—	Ration A		Ration B		Ration C	
	CaO	P_2O_5	CaO	P_2O_5	CaO	P_2O_5
With lime supplement	·693	1·514	·727	1·189	·783	·623
Without supplement	·467	1·616	·507	1·164	·529	·575

Judging by diets used for rat experiments by other workers, the unsupplemented rations are somewhat low in lime and ration C is low in phosphoric acid. Such low $P_2 O_5$ values will be obtained generally in India unless wheat bran or rice bran is used as part of the concentrate.

Nitrogen balances.

The results of the nitrogen balance experiments are given in a condensed form in the accompanying Table.

Table XVII.

Nitrogen balances in grams per day.

Silage	Ration A			Ration B			Ration C		
	Calf	Live weight	Nitrogen balance	Calf	Live weight	Nitrogen balance	Calf	Live weight	Nitrogen balance
I . .	1	243	16·59	3	220	16·98	5	234	12·74
	2	178	13·12	4	185	12·99	6	166	10·59
II . .	7	216	18·65	9	275	19·27	11	254	15·94
	8	234	20·86	10	188	19·05	12	176	11·99
III .	7	216	18·23	9	275	20·92	11	254	9·49
	8	234	17·04	10	188	17·45	12	176	9·52
	13	222	14·32	15	240	16·00	17	215	8·85
	14	188	9·56	16	152	9·65	18	177	..
IV . .	13	222	14·66	18	240	16·51	17	215	6·74
	14	188	11·84	16	152	10·84	18	177	7·67
Average.		214	15·51		212	15·96		204	10·39

The following points may be noticed in these results :—

1. Under each ration the assimilation is generally higher with animals of greater live weight.
2. The averages for the three rations show that the C group generally assimilated somewhat less than groups A and B.
3. The figures for the third batch of calves (Nos. 13 to 18) are below the average.

In all these cases, the nitrogen balance is roughly parallel to the rate of live weight increase. To this extent, the determination is a useful supplement to the live weight figures. Regarding the influence of the quality of the silage upon nitrogen assimilation, the table shows that this possible factor had no appreciable effect

on the result. The nitrogen balance data give us some information concerning the requirements of crude protein for growth. The average utilization of crude protein nitrogen by the three groups is given in the next Table.

TABLE XVIII.

Average utilization of crude protein nitrogen in grams per day.

	Ration A	Ration B	Ration C
Nitrogen in roughage . . . grams	12·04	14·03	15·72
Nitrogen in concentrate . . . „	35·28	55·43	42·37
Total nitrogen in ration . . . „	47·32	61·46	58·09
Nitrogen in fæces . . . . „	19·83	20·34	20·78
Nitrogen digested . . . . „	27·49	49·12	37·31
Nitrogen excreted in urine . . „	11·98	33·16	26·92
Nitrogen assimilated . . . „	15·51	15·96	10·39
Per cent. assimilation of digested nitrogen.	56·4	32·5	27·9

From these figures it appears that when wheat bran is the sole concentrate, 27·49 grams of digestible crude protein nitrogen are sufficient to support rapid growth in calves weighing 212 lb., 15·5 grams were retained and 12 grams were voided in the urine. With the other rations the waste was much greater. This may be due either to the fact that we fed more protein than the animals could utilize or that the proteins of rations B and C were less efficient physiologically. If the latter reason were correct, the utilization of nitrogen in ration B, which contained two parts bran to one part of cake, should be superior to ration C which contained practically only groundnut protein. The actual difference found between rations B and C is so small that it does not leave room for any appreciable physiological difference. We conclude, therefore, that the low per cent. utilization of nitrogen in rations B and C was due mainly to the circumstance that we fed more protein than the animals could utilize.

Nitrogen distribution in urine.

The distribution of urinary nitrogen was determined 16 times on each ration. Appreciable variations were observed in individual tests. The following average results were obtained :—

TABLE XIX.

Distribution of urinary nitrogen.

—	Total nitrogen	Urea	Amino nitrogen	Creatine nitrogen	Undetermined nitrogen
Ration A	12·53	7·63	·876	·951	3·282
„ B	35·36	28·92	·956	1·384	4·096
„ C	28·01	21·80	1·491	1·074	3·522

It appears from these figures that the creatine and creatinine nitrogen is related to the amount of protein in the ration. The amino acid nitrogen which consists almost wholly of hippuric acid seems to depend to some extent on the amount of roughage consumed. The relative figures for amino acid excretion and roughage consumed are as follows :—

	Amino acid	Roughage consumed
Ration A	1	1
„ B	1·09	1·20
„ C	1·70	1·42

The undetermined nitrogen is roughly proportional to creatine and creatinine.

Summary.

1. The amount of food consumed by healthy calves of uniform breed was found to be remarkably regular in various respects. The high rate of food consumption attained in the experiment is attributed to the quality of the food.

2. *Sorghum* silage fed *ad lib.* together with suitable concentrate produced very rapid growth with Scindi calves.

3. Numerous digestion experiments showed that the rations were very well digested. No other ration tested by the Nutrition Section has given results to approach these figures. The high digestion attained is attributed to the quality of the *Sorghum* silage.

4. The high rate of live weight increase is adequately accounted for by the digestion results.

5. The digestion of protein was found to be proportional to the amount of protein in the ration. The quantities digested could not be explained satisfactorily on the assumption of constant digestion coefficients.

6. Assimilation of the digested nitrogen was efficient to the extent of 56 per cent. when wheat bran formed the sole concentrate. With the other rations the waste

was greater. The low utilization in these cases appears to have been due mainly to the fact that we fed more protein than the animals could utilize.

7. With regard to assimilation of minerals, it was found that the animals assimilated P_2O_5 very consistently in proportion to the amount present in the food. A curious fact was observed in connection with lime assimilation. It was found that assimilation was high in the early stages and fell off as the course of feeding progressed. There was no connection between the rates of assimilation of lime and phosphoric acid.

8. A batch of calves which did not receive a lime supplement failed to grow rapidly, but the failure could not be attributed definitely to a shortage of lime. This test was inconclusive.

Acknowledgment.

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APPENDIX.

Table I.

Average daily roughage consumption, 1st batch.

(Oven dry weight in Kilos.)

Calf No.	1	2	3	4	5	6
1st week	4·643	3·637	5·270	5·411	7·212	7·799
2nd ,,	5·139	4·803	5·853	6·516	7·556	7·112
3rd ,,	7·628	6·786	8·465	8·099	8·969	8·166
4th ,,	6·351	6·106	7·785	7·829	8·252	7·785
5th ,,	6·834	6·254	8·226	8·107	8·910	8·145
6th ,,	8·200	7·726	9·673	8·271	9·794	8·104
7th ,,	8·802	8·453	10·993	9·184	11·157	9·020
8th ,,	8·322	7·650	10·235	9·284	11·212	9·330
9th ,,	8·488	8·171	9·035	8·589	10·714	7·802
10th ,,	8·088	8·842	9·214	9·439	12·111	8·925
11th ,,	7·291	8·972	7·849	9·248	10·562	8·706
12th ,,	9·778	10·581	10·381	10·313	12·794	10·886
	89·564	87·981	102·979	100·290	119·243	101·780

Average daily consumption of concentrate, 1st batch.

(Air dry weight in Kilos.)

Calf No.	1	2	3	4	5	6
1st week	13·476	9·681	9·001	7·140	6·720	3·511
2nd ,,	11·920	8·670	9·100	7·140	6·720	3·580
3rd ,,	9·800	7·860	9·100	7·140	6·720	3·920
4th ,,	12·320	9·520	9·100	7·140	6·720	3·920
5th ,,	12·320	9·520	9·100	7·140	6·720	3·920
6th ,,	12·320	9·520	9·100	7·140	6·720	3·920
7th ,,	12·320	9·520	9·100	7·140	6·720	3·920
8th ,,	12·320	9·520	9·100	7·140	6·720	3·920
9th ,,	14·650	11·278	11·290	8·864	8·050	5·462
10th ,,	16·520	12·068	12·180	10·164	8·400	5·922
11th ,,	17·920	13·216	12·852	10·976	8·974	6·258
12th ,,	17·920	13·216	12·852	10·976	8·974	6·258
	163·806	123·289	121·865	98·100	88·158	54·511

TABLE I—*contd.*

Average daily roughage consumption, 2nd batch.

Calf No.	7	8	9	10	11	12
1st week	5·676	5·241	8·763	5·850	8·942	6·387
2nd "	5·764	5·240	10·674	6·273	10·189	7·683
3rd "	5·755	5·681	11·028	7·005	10·893	7·781
4th "	6·081	5·501	10·664	7·234	9·409	7·723
5th "	6·723	6·405	10·736	8·436	11·592	8·637
6th "	7·406	7·225	10·589	6·707	11·022	8·856
7th "	8·765	7·729	10·141	8·486	13·569	10·170
8th "	8·187	9·767	11·257	8·605	13·020	10·249
9th "	7·274	7·241	9·346	7·420	10·568	8·750
10th "	7·601	7·292	10·848	8·000	10·763	8·539
11th "	9·190	8·064	12·446	9·149	12·005	10·395
12th "	9·619	9·253	13·734	9·850	13·773	10·529
13th "	9·116	9·033	12·448	9·047	12·109	10·062
14th "	7·328	7·090	9·897	7·235	9·874	8·616*
	104·490	100·762	152·571	109·297	157·728	124·377

* 5 days.

Average daily consumption of concentrate, 2nd batch.

Calf No.	7	8	9	10	11	12
1st week	9·912	10·794	10·164	6·804	6·776	4·536
2nd "	9·912	10·794	10·164	6·804	6·776	4·536
3rd "	9·912	10·794	10·164	6·804	6·776	4·536
4th "	9·912	10·794	10·164	6·804	6·776	4·536
5th "	11·760	12·390	12·194	8·232	7·784	5·418
6th "	12·560	13·440	13·140	9·062	8·336	5·722
7th "	12·950	13·860	13·940	9·380	8·540	5·950
8th "	12·950	13·860	13·940	9·380	8·540	5·950
9th "	13·650	14·910	14·000	9·940	8·820	6·132
10th "	13·650	14·910	14·000	9·940	8·820	6·132
11th "	14·770	16·170	14·980	10·640	9·240	6·370
12th "	14·770	16·170	14·980	10·640	9·240	6·370
13th "	14·770	16·170	14·980	10·640	9·240	6·370
14th "	12·660	13·860	12·840	9·120	7·920	5·460*
	174·138	188·916	178·650	124·190	113·584	78·018

* 5 days.

TABLE I.—*contd.*

Average daily roughage consumption, 3rd batch.

Calf No.	13	14	15	16	17	18
1st week	4·774	3·787	6·268	4·242	8·160	6·180
2nd ,, ...	3·991	4·308	7·151	4·806	8·553	6·426
3rd ,, ...	6·861	5·871	8·994	5·956	10·289	8·460
4th ,, ...	7·766	6·560	9·780	7·239	11·371	9·880
5th ,, ...	7·881	6·047	9·047	6·606	10·635	9·245
6th ,, ...	7·406	5·561	8·442	6·580	9·547	8·577
7th ,, ...	6·548	4·558	8·558	6·634	10·136	9·026
8th ,, ...	6·363	4·721	9·171	7·065	10·366	9·569
9th ,, ...	7·686	6·157	9·447	7·622	9·995	9·701
10th ,, ...	7·463	6·078	9·422	7·812	9·722	9·634
11th ,, ...	6·267	4·795	8·003	6·880	8·674	8·128
12th ,, ...	6·616	5·772	8·713	6·861	8·614	9·217
13th ,, ...	6·529	5·729	8·354	6·753	8·843	9·109
14th ,, ...	6·707	5·871	8·820	6·912	9·934	9·935
	92·838	75·815	120·170	91·968	134·839	123·087

Average daily consumption of concentrate, 3rd batch.

Calf No.	13	14	15	16	17	18
1st week	11·760	8·750	9·380	5·880	6·202	5·012
2nd ,, ...	11·760	8·750	9·380	5·880	6·202	5·012
3rd ,, ...	11·970	9·380	10·080	6·230	6·510	5·250
4th ,, ...	11·970	9·380	10·080	6·230	6·510	5·250
5th ,, ...	11·970	9·380	10·080	6·230	6·510	5·250
6th ,, ...	11·970	9·380	10·080	6·230	6·510	5·250
7th ,, ...	14·280	11·060	11·690	7·140	7·280	5·922
8th ,, ...	14·280	11·060	11·690	7·140	7·280	5·922
9th ,, ...	14·280	11·060	11·690	7·140	7·280	5·922
10th ,, ...	14·280	11·060	11·690	7·140	7·280	5·922
11th ,, ...	15·080	12·160	12·940	8·040	7·580	6·342
12th ,, ...	15·400	12·600	13·440	8·400	7·700	6·510
13th ,, ...	15·400	12·600	13·440	8·400	7·700	6·510
14th ,, ...	15·890	13·580	14·280	9·100	7·980	6·776
	190·290	150·200	159·940	99·180	98·524	80·850

TABLE II.

Weekly average live weights in lb. (1st batch).

Calf No.	1	2	3	4	5	6
1st week	190·4	134·9	174·0	142·9	191·6	137·1
2nd ,, ...	206·0	146·3	185·0	156·3	205·7	146·7
3rd ,, ...	214·0	153·1	194·7	165·0	214·0	150·0
4th ,, ...	222·1	157·9	203·4	170·1	216·6	151·1
5th ,, ...	228·9	164·9	210·7	175·3	224·0	156·0
6th ,, ...	..	..	..	..	..	..
7th ,, ...	..	..	..	..	..	..
8th ,, ...	259·2	189·2	238·7	196·7	246·8	173·5
9th ,, ...	266·6	195·4	245·3	202·7	254·4	179·0
10th ,, ...	276·9	206·4	251·0	213·6	261·9	181·0
11th ,, ...	283·4	212·4	257·6	219·7	266·6	187·7
12th ,, ...	296·0	220·4	165·9	227·0	276·0	195·8

Weekly average live weights in lb. (2nd batch).

Calf No.	7	8	9	10	11	12
1st week	162·6	174·9	214·6	140·0	209·1	140·3
2nd ,, ...	168·0	181·3	224·0	147·3	218·3	144·4
3rd ,, ...	174·9	189·4	232·3	154·9	223·9	148·7
4th ,, ...	182·9	194·6	240·3	163·0	228·7	154·7
5th ,, ...	188·4	201·7	246·3	168·1	233·9	159·7
6th ,, ...	194·6	208·9	257·9	174·9	242·0	163·7
7th ,, ...	199·7	216·3	262·0	178·0	245·7	167·3
8th ,, ...	214·5	234·5	273·5	193·0	260·5	175·0
9th ,, ...	222·1	242·4	280·1	198·0	263·0	182·4
10th ,, ...	230·1	252·0	287·6	205·6	270·4	187·1
11th ,, ...	238·4	258·1	300·1	213·6	275·0	191·3
12th ,, ...	..	..	..	..	..	..
13th ,, ...	261·0	283·0	326·7	231·0	194·0	202·7
14th ,, ...	268·4	293·0	335·1	236·3	298·3	210·7

TABLE II.—*concld.*

Weekly average live weight in lb. (3rd batch).

Calf No.	13	14	15	16	17	18
1st week	187	144	190	118	187	149
2nd „	185	146	197	122	192	152
3rd „	195	155	204	126	199	158
4th „	..	..	..	..	..	..
5th „	216	171	222	137	211	170
6th „	222	176	229	141	214	175
7th „	224	176	234	146	216	176
8th „	227	181	243	151	221	180
9th „	231	186	250	155	225	185
10th „	239	196	263	165	229	192
11th „	242	202	267	166	229	193
12th „	247	207	274	171	233	197
13th „	250	214	280	177	236	199
14th „	256	221	190	186	242	204

CONTENTS

FOREWORD.

The work described in the following Memoir has been carried out during the past two years. The Senior Author is leaving India and will be unable to continue in charge of the investigations. It is, therefore, considered advisable to publish the results so far obtained. The work will, however, be continued by the joint authors of the paper.

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LOSSES AND GAINS OF NITROGEN IN AN INDIAN SOIL STUDIED IN RELATION TO SEASONAL COMPOSITION OF WELL WATERS, AND THE BEARINGS OF THE RESULTS ON THE ALLEGED DETERIORATION OF SOIL FERTILITY.

BY

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Much work has been carried out on nitrification and nitrogen fixation in soils in various countries. Most of the work on nitrification deals with the conditions affecting the process and figures have been given showing the amount of nitrate in the soil at various depths throughout the year. What happens to this nitrate after formation has received much less attention. Most writers assume that what is not used by the plant passes away into the subsoil water. It is certainly widely stated that little denitrification takes place in soils. The work carried out in this laboratory shows that the loss of nitrate from soils is very great and in view of various other interesting observations arising out of the work no apology seems needed for adding to the already vast literature on the subject. Much of the work on nitrification has been carried out on soils, the formations underlying which allow the subsoil water to pass rapidly away into neighbouring rivers. In the area on which our work has been carried out, we have a fairly uniform heavy black clay—the black cotton soil of India—40 to 50′ in depth resting on trap rock. In the rains the water level in wells rises to about 3 feet from the surface and in the hot weather it falls to a distance of 19 feet from the surface. These conditions are typical of a very large tract of country in the Central Provinces of India though the water levels and depth of soil vary in different parts. There will of course be lateral movement of this under-ground water supply towards the big river beds. Since there are no

big rivers near the Nagpur Farm, the probability is that the lateral movement is exceedingly slow. It occurred to us, therefore, that a study of the nitrate content of wells, undertaken in connection with a study of the nitrate content of the soil itself at various periods throughout the year, should give interesting results. Our experiments fall naturally into 3 divisions.

I. A study of the nitrate content of the top 3 feet of soil of various plots at frequent intervals throughout the year. These experiments have been carried on from June 1925 to date, January 1927. With this was included a study of the total nitrogen content of the top one foot of soil.

II. A study of two wells throughout the year, one of which is used for irrigation and one of which is not used at all. Regular determinations of well levels, total solids, nitrates, carbonates and bicarbonates were made.

III. A study of the nitrate content of the drainage water from the drains laid under these plots.

For the convenience of the reader unacquainted with the soil and climate of the Central Provinces of India, the following particulars are given. They relate to the head-quarters station, Nagpur.

Temperature at Nagpur in 1926.

—	Months											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Maximum	88·5	99·6	101·8	109·7	111·7	114·0	102·6	92·6	94·0	92·9	91·5	90·3
Minimum	49·3	47·0	58·2	65·9	69·0	78·6	72·3	73·0	72·0	56·1	49·2	43·8
Rainfall.												
Normal	·58	·56	·46	·50	·69	8·76	13·48	10·66	7·85	2·09	·56	·46
Total for year	..	..	..	..	..	..	..	..	..	..	..	46·65

Mechanical analysis.

Clay	42·5
Fine silt	19·6
Silt	12·5
Fine sand	7·4
Coarse sand	10·2
Moisture	3·3
Loss on ignition	3·0
Calcium carbonate	1·6
	100·1

Chemical analysis.

Fe_2O_3	11·25
Al_2O_3	9·39
MnO	0·26
CaO	1·82
MgO	1·79
K_2O / Na_2O	0·45
P_2O_5	0·06
SO_3	*Nil*
CO_2	0·44
Insoluble silicates and sand	68·71
Organic matter and combined water*	5·83
Total	100·00

* Containing total nitrogen	0·050
Available P_2O_5	0·008
,, K_2O	0·041

PART I.

A STUDY OF THE NITRATE CONTENT OF THE TOP 3 FEET OF SOIL OF VARIOUS PLOTS AT FREQUENT INTERVALS THROUGHOUT THE YEAR.

After this study was started, it was found necessary to increase the scope of the experiment on two subsequent occasions and therefore the experiment must be separately described for each of these periods.

PERIOD (*a*). 21ST JUNE 1925—8TH APRIL 1926.

During this period two plots only were taken under observation. Both of these had been regularly cropped for years past with cotton and *juar* (*sorghum vulgare*) in alternate years, except for an occasional crop of sann hemp (*Crotalaria juncea*) or *Tur* (*Cajanus indicus*). One of them has received no manure in the history of the farm, certainly not during the past 25 years, and the other has received regularly every year a dressing of 4 tons per acre of cattle dung and in addition is topdressed during the growing season with nitrate of soda at the rate of 65 lb. per acre. The plots run north and south and each measures $\frac{1}{5}$th acre in area. The yields on these two plots for the past 5 years have been :—

	Yield per acre lb.				
	1922	1923	1924	1925	1926
	Cotton	*Juar*	Sann hemp	Cotton	*Juar*
Unmanured	281¼	7,005	7,125	375	7,615
Manured	500	13,365	8,125	660	11,785

The yield of cotton refers to kapas, *i.e.*, seed and lint, whereas the *juar* yield refers to green fodder. The figure shown for sann hemp refers to weight of fibre.

The plots are under-drained with tile drains at a depth of $2\frac{1}{2}$ feet. The outfall is bricked and the drainage of each area can be collected separately.

PERIOD (*b*). 16TH APRIL 1926—28TH OCTOBER 1926.

It was felt advisable to include an uncropped plot in the experiment. This was done from 16th April 1926. Between the 2 plots already under experiment was an exactly similar plot also under-drained which had received no manure for many years past. This was divided lengthwise into two sub-plots. Both these plots were left fallow. One remained unmanured and the other received a dressing of cattle manure on 16th June 1926 just before the rains. On this same date the manured plot which was to be cropped also had a similar dressing of cattle manure. The experiment, therefore, from now on included 4 plots.

1. Uncropped unmanured.
2. Uncropped manured.
3. Cropped unmanured.
4. Cropped manured.

PERIOD (*c*). 1ST NOVEMBER 1926 TO DATE, JANUARY 1927.

It was decided at this date to study the effect of cultivation at the close of the rains on nitrate formation in the soil during the cold weather. The uncropped unmanured and uncropped manured plots were, therefore, again subdivided and one-half of each was cultivated as described later.

Unfortunately, the land had been left too long and was too dry for efficient cultivation. Fortunately, a neighbouring field which was uncropped during the rains had been regularly cultivated at the close of the rains. It had been unmanured for years and was apparently similar in every way to the plots already under experiment. It was decided to sample this plot regularly from 1st November 1926 onwards with the other plots. It was left uncropped and is called plot III in the tables. Therefore from 1st November 1926 the following plots were under experiment :—

1. Uncropped unmanured uncultivated.
2. Uncropped manured uncultivated.
3. Cropped unmanured uncultivated.
4. Cropped manured uncultivated.
5. Uncropped unmanured cultivated.
6. Uncropped manured cultivated.
7. Plot III uncropped unmanured cultivated.

The crop (*juar*) was removed from 3 and 4 on 13th November 1926. No. 7 differs from 5 and 6 in that it received regular cultivation after the rains ceased as though in preparation for a cold weather crop, whereas Nos. 5 and 6 were left too late and in consequence became too dry for efficient cultivation. They were weeded on 29th October and broken up by a heavy plough on 29th October. They were *bakhared*[1] on the 31st October. Very large clods were left and these were broken down by hand on 5th November. A clod crusher was run over the land on 12th November, but even then the surface soil was simply a mass of large hard lumps.

METHOD OF SOIL SAMPLING.

Owing to its heavy nature the soil is a difficult one to sample, especially when it is drying out. We have found the only practicable way is to take the top and the second 6″ sample with an ordinary cylindrical boring tube with sharp edges. For the next two portions of 6″ each a large auger is employed and for the 5th and 6th portions of 6″ a smaller auger is used. It would be desirable to follow the changes in nitrate content to a greater depth than 3 feet, but we have so far found no convenient method of sampling black cotton soil to a greater depth than this. At each sampling 4 borings were taken in each plot and they were combined to form one set of samples corresponding to each 6″ depth of soil. The borings were always taken on a line drawn across the middle of the plots breadthwise and each subsequent line of samples was taken approximately 1 foot further south of the preceding line of samples. After about 6 months the line of sampling was shifted back to the original line and then sampling proceeded as before. Thus it will be seen that all samples were taken in a narrow rectangle running breadthwise across the plots and reaching approximately 10 or 12 feet lengthwise along the plots.

In order to get an idea of the experimental error, the four sub-samples were analysed separately in certain cases and the results of these analyses are given later (Table IV).

METHOD OF ANALYSIS.

The samples were placed in airtight bottles in the field and removed to the laboratory as rapidly as possible. The samples were in each case rapidly mixed and broken down in the laboratory. 50 grm. were weighed off for moisture estimation and dried for 12 hours before weighment, a second weighment being taken after 3 hours' further drying.

NITRATES.

Nitrate was estimated by the phenoldisulphonic acid method. 100 grm. of the sample were placed in a wide mouthed bottle fitted with a rubber stopper and a small amount of gypsum together with 300 c.c. water was added. The stopper

[1] Bakhar—a bladed harrow.

was inserted and the bottle shaken until the sample was completely broken down. The disintegration of the lumps was assisted where necessary by rubbing down with a rubber pestle. The liquid was filtered through Whatman's No. 1 filter paper,[1] which does not absorb nitrate. A convenient volume of the filtrate usually 100 c.c., the actual volume depending on the nitrate concentration expected, was evaporated to dryness in a porcelain basin. 2 c.c. of phenoldisulphonic acid was added, the residue being thoroughly wetted with the reagent. The basin was then heated on the water bath for 3 minutes, after which the contents were washed into a measuring cylinder with water. 10 c.c. of strong ammonia was added and the volume made up to 100 c.c. with water. After shaking, the cylinder was allowed to stand for 5 minutes and the depth of colour was matched against standard yellow glasses in a Lovibond's tintometer—these glasses having been previously standardised against pure nitrate solutions. The phenoldisulphonic acid method of nitrate estimation has been frequently criticised, but our experience of it is that when carefully carried out, it gives results of sufficient accuracy for ordinary soil investigations. The number of determinations carried out in our work was so great as to preclude the use of a reduction method which involved either the subsequent volumetric measure of nitric oxide, or a distillation of ammonia.

Total nitrogen.

This was determined by the ordinary Kjeldahl method on 20 grm. of the soil, copper sulphate and potassium sulphate being added in the usual manner. Moist samples of soil were always used as it has been shown in this laboratory that air-dry samples of heavy black cotton soil do not yield up the whole of their nitrogen in the Kjeldahl process.* In certain published work on nitrogen fixation, it would appear that the original soil has been analysed for total nitrogen in the air-dry condition. Various portions were then weighed off and left for varying periods with added amounts of water. The total nitrogen in these moist samples was then estimated and the increase found was ascribed to nitrogen fixation, whereas it could be largely accounted for by the difference in nitrogen content found by analysing the soil in the dry and moist condition. Early experiments on nitrogen fixation carried out in our own laboratory have been discarded, because it was not realised at the time that air-dry soil does not yield the whole of its nitrogen in the Kjeldahl process.

Rainfall.

A careful record of the rainfall was maintained throughout the duration of the experiment. The figures are given in Table V and are also plotted on the charts.

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[1] Gimingham has shown that certain brands of filter paper absorb nitrates. *Jour. Agri. Sci.*, Vol. XIII, pp. 60-62, 1923.

* Bal, D. V. *Jour. Agri. Sci.*, XV, pp. 454-459, 1925.

Drainage.

A note was kept of the dates on which the drains were running and analyses were regularly made of the nitrate content of the drainage water. These results will be referred to in Part III.

Cultural operations.

These are set out below.

In the season 1925 the crop on the plots was cotton. The plots were all fallow throughout the cold weather 1925-26. The crop on the cropped plots in 1926 was *juar* (*sorghum vulgare*).

1925.

—	Manured plot	Unmanured plot
June, 7th	Spreading manure	....
„ 8th	Bakharing	Bakharing
„ 18th	„	„
„ 19th	Sowing	Sowing
July, 8th	Hoeing	Hoeing
„ 15th	Weeding	Weeding
August, 17th	....	Hoeing
„ 20th	Top-dressing	....
„ 22nd	Hoeing	....
October, 27th	Cotton picking	Cotton picking
November, 26th	„ „	„ „
December, 27th	„ „	„ „

1926.

Plot No.	1	2	3	4	5	6	7
March, 3rd	..	Disc ploughing by tractor			..	..	..
May, 27th	..	Bakharing by bullocks			..	..	..
June, 7th	..	Bakharing by tractor			..	..	..
,, 17th	Bakharing	Manuring and Bakharing	Bakharing	Manuring and Bakharing	Bakharing	Manuring and Bakharing	Bakharing
July, 6th	..	..	Bakharing by bullocks		..	..	..
,, 7th	..	..	Harrowing	..	..	..	..
,, 9th	..	..	Sowing	Sowing	..	..	..
,, 18th	..	..	..	..	..	..	Bakharing
Sep., 12th	..	..	..	..	..	..	Tractor Bakharing and Spring tooth cultivation
,, 24th	..	..	..	..	..	..	Ditto
Oct., 19th	..	..	..	..	..	..	Bakharing
,, 22nd	..	..	..	..	..	..	Harrowing
,, 28th			Weeding				..
,, 29th	..	..	..	..	Weeding and ploughing		..
,, 31st	..	..	..	..	Bakharing		..
Nov., 5th	..	..	..	..	Clods broken by hand		..
,, 12th	..	..	..	..	Clod crusher working		..
,, 13th	..	..	Harvesting fodder		..	..	..

The results obtained are set out in the following tables. Table I gives the results for the period (*a*) from 21st June 1925 to 6th April 1926. As already stated two plots only were under experiment during this period, one being manured and the other unmanured. The remarks column shows the dates of various cultural operations, manurial applications, date of sowing, height of crop at various dates, date of harvest, etc. The Table gives the water content of the soil at each sampling and also expresses the amount of nitrate in the soil. For convenience, this is expressed in 2 ways, firstly as grm. of nitrate of soda per 100 grm. dry soil and secondly as lb. of nitrate of soda per acre. For the purpose of the second method of expression an acre of dry soil 6″ deep has been assumed to weigh 1,500,000 lb.

TABLE I. PERIOD (a).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926.

Date	Depth	Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
21st June 1925	0—6″	34·0	·0034	51·21	34·6	·0043	64·3
	6—12″	20·0	·0019	27·91	17·7	·0014	21·78
	12—18″	21·4	·00094	14·14	20·7	·0019	28·09
	18—24″	23·3	·0011	17·31	22·0	·0017	25·63
	24—30″	26·1	·00	0·00	25·2	·0012	17·64
	30—36″	22·9	·00	0·00	25·9	·0012	17·79
				110·57			175·23
25th June 1925	0—6″	33·40	·0021	31·81	32·2	·0025	37·38
	6—12″	31·7	·0029	43·86	32·1	·0071	106·90
	12—18″	30·3	·0041	61·86	30·7	·0045	68·29
	18—24″	26·9	·0044	65·82	25·9	·0031	47·11
	24—30″	32·8	·0013	18·99	23·0	·0031	46·00
	30—36″	27·0	·0012	17·97	24·7	·0023	35·13
				240·31			340·81
1st July 1925	0—6″	36·6	·0017	26·22	36·5	·0017	26·17
	6—12″	34·8	·0021	32·22	35·7	·0022	32·49
	12—18″	34·1	·0043	64·06	33·9	·0064	95·89
	18—24″	32·4	·0046	69·39	33·1	·0021	31·71
	24—30″	29·8	·0016	24·63	30·1	·0029	43·20
	30—36″	28·8	·0016	24·39	28·9	·0045	67·12
				240·91			296·58
8th July 1925	0—6″	38·8	·0024	36·75	37·3	·0022	32·98
	6—12″	36·8	·0025	39·39	37·5	·0026	39·63
	12—18″	34·8	·0032	48·36	34·8	·0039	58·02
	18—24″	34·7	·0030	45·10	33·5	·0055	82·81
	24—30″	34·4	·0026	38·53	32·5	·0034	50·47
	30—36″	35·0	·0024	35·52	31·4	·0033	49·98
				243·65			313·89
15th July 1925	0—6″	38·6	·0013	20·01	39·5	·0018	26·89
	6—12″	37·4	·0013	19·78	36·1	·0017	26·10
	12—18″	36·4	·0013	19·62	34·8	·0013	19·35
	18—24″	36·1	·0013	19·57	35·3	·0022	32·37
	24—30″	35·4	·0013	19·45	35·1	·0021	32·32
	30—36″	36·4	·0022	32·71	35·8	·0022	32·53
				131·14			169·56

TABLE I. PERIOD (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926—contd.

Date	Depth	Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per, 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
22nd July 1925	0—6″	37·3	·0031	46·15	38·6	·0027	40·02
	6—12″	36·0	·0015	22·83	36·2	·0017	26·13
	12—18″	35·0	·0017	25·83	33·7	·0021	31·90
	18—24″	35·5	·0022	32·44	34·8	·0021	32·23
	24—30″	35·5	·0019	29·19	36·5	·0048	72·06
	30—36″	34·6	·0021	32·17	36·3	·0054	81·67
				188·61			284·01
30th July 1925	0—6″	44·0	·00087	13·00	40·8	·00084	12·65
	6—12″	42·2	·0010	14·94	36·2	·00099	14·86
	12—18″	39·7	·00099	14·63	36·7	·00067	10·05
	18—24″	39·6	·00099	14·63	37·9	·00069	10·36
	24—30″	38·3	·00096	14·45	37·9	·0025	37·99
	30—36″	36·2	·00094	14·18	33·7	·0040	59·41
				85·83			145·32
3rd August 1925	0—6″	37·2	·0011	16·35	36·9	·00095	14·26
	6—12″	36·3	·00081	12·16	34·6	·00093	13·97
	12—18″	36·6	·00068	10·16	32·3	·0011	16·08
	18—24″	36·4	·00068	10·14	34·8	·0011	16·00
	24—30″	34·8	·00027	4·00	35·1	·00094	14·04
	30—36″	35·3	·0011	16·08	36·6	·0013	20·32
				68·89			94·67
13th August 1925	0—6″	39·1	·0017	24·94	38·0	·00082	12·35
	6—12″	38·4	·0014	20·67	35·3	·00080	12·06
	12—18″	35·8	·0013	20·17	34·8	·00093	14·00
	18—24″	37·4	·0014	20·49	34·5	·00080	11·95
	24—30″	37·8	·0018	26·97	37·3	·0012	18·42
	30—36″	38·9	·0018	27·24	36·5	·0012	18·27
				140·48			87·05
20th August 1925	0—6″	39·1	·00083	12·50	41·5	·0015	23·34
	6—12″	41·5	·00071	10·61	39·2	·00090	13·49
	12—18″	41·4	·00085	12·72	36·2	·00094	14·18
	18—24″	39·3	·00083	12·50	37·3	·00068	10·23
	24—30″	38·3	·00096	14·45	36·1	·00067	10·12
	30—36″	39·5	·00090	13·51	35·8	·00054	8·07
				76·29			79·43

TABLE I. PERIOD (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926—contd.

Date	Depth	Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
27th August 1925	0—6″	41·5	·00099	14·85	41·3	·0014	21·19
	6—12″	38·7	·00076	11·39	38·9	·0013	19·70
	12—18″	37·9	·00075	11·32	38·7	·0012	18·64
	18—24″	36·4	·00054	8·12	37·3	·00083	12·28
	24—30″	37·5	·00048	7·17	38·6	·0010	15·50
	30—36″	38·3	·00055	8·26	39·3	·0013	19·79
				61·11			107·10
3rd September 1925	0—6″	40·6	·0010	15·80	40·1	·0013	19·92
	6—12″	37·9	·00075	11·31	37·6	·0011	16·40
	12—18″	37·5	·00068	10·25	36·5	·00088	13·20
	18—24″	36·8	·00088	13·24	36·4	·00081	12·18
	24—30″	36·3	·00068	10·14	37·2	·00075	11·24
	30—36″	37·0	·00075	11·22	37·5	·00068	10·25
				71·96			83·19
10th September 1925	0—6″	36·0	.0011	16·18	36·4	·0011	16·23
	6—12″	33·4	·00079	11·85	33·5	·0010	15·81
	12—18″	33·3	·00072	10·86	33·1	·00079	11·81
	18—24″	33·6	·00079	11·88	33·3	·00066	9·87
	24—30″	40·0	·00078	11·51	37·6	·00068	10·25
	30—36″	38·4	·00076	11·36	38·5	·00070	10·34
				73·64			74·31
16th September 1925	0—6″	39·4	·00085	12·79	31·6	·00097	14·57
	6—12″	32·6	·00059	8·82	31·1	·00084	12·56
	12—18″	32·5	·00059	8·81	30·8	·00058	8·68
	18—24″	34·1	·00053	7·95	31·5	·00045	6·79
	24—30″	35·5	·00047	7·04	35·3	·00040	6·03
	30—36″	33·4	·00046	6·91	35·9	·00040	6·06
				52·32			54·69
23rd September 1925	0—6″	37·0	·00010	15·30	34·0	·0012	17·87
	6—12″	32·9	·00065	9·83	31·4	·00084	12·60
	12—18″	32·2	·00072	10·74	30·5	·00058	8·65
	18—24″	32·9	·00065	9·83	31·2	·00045	6·77
	24—30″	35·9	·00067	10·10	35·4	·00047	7·03
	30—36″	37·0	·00075	11·22	37·1	·00095	14·30
				67·02			67·22

Table I. Period (a).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926—contd.

Date	Depth	Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
2nd October 1925	0—6″	28·9	·00038	5·68	31·9	·00071	10·71
	6—12″	29·8	·00051	7·64	28·4	·00050	7·53
	12—18″	30·4	·00051	7·68	28·2	·00044	6·58
	18—24″	31·1	·00039	5·80	30·4	·00070	10·56
	24—30″	35·1	·00040	6·02	34·2	·00053	7·96
	30—36″	37·1	·00041	6·13	34·4	·00046	6·98
				38·95			50·32
7th October 1925	0—6″	27·5	·00044	6·54	26·7	·00062	9·26
	6—12″	26·7	·00037	5·56	29·0	·00057	8·53
	12—18″	28·2	·00044	6·58	30·4	·00045	6·72
	18—24″	31·3	·00032	4·84	32·1	·00039	5·85
	24—30″	36·1	·00040	6·07	34·7	·00033	5·00
	30—36″	36·2	·00040	6·08	34·5	·00033	4·99
				35·67			40·35
14th October 1925	0—6″	27·8	·00044	6·56	24·8	·00055	8·18
	6—12″	26·7	·00037	5·56	25·7	·00043	6·42
	12—18″	28·2	·00031	4·70	30·3	·00032	4·79
	18—24″	29·6	·00025	3·81	30·0	·00032	4·78
	24—30″	33·9	·00033	4·96	33·3	·00033	4·93
	30—36″	34·7	·00033	5·00	29·5	·00032	4·76
				30·59			33·86
21st October 1925	0—6″	31·1	·00048	7·26	30·7	·00058	8·67
	6—12″	30·1	·00038	5·74	28·3	·00038	5·64
	12—18″	29·7	·00032	4·77	27·3	·00031	4·66
	18—24″	31·3	·00032	4·84	28·5	·00025	3·77
	24—30″	33·0	·00033	4·92	34·6	·00027	3·99
	30—36″	35·6	·00034	5·03	33·0	·00026	3·93
				32·56			30·66
28th October 1925	0—6″	29·8	·0013	19·09	28·6	·0020	30·20
	6—12″	29·3	·00076	11·40	27·2	·00099	14·89
	12—18″	28·5	·00063	9·43	26·1	·00086	12·89
	18—24″	29·9	·00025	3·82	26·9	·00056	8·35
	24—30″	32·9	·00026	3·93	30·7	·00064	9·63
	30—36″	31·6	·00026	3·89	31·9	·00058	8·76
				51·56			84·72

TABLE I. PERIOD (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926—contd.

Date	Depth	Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm per. 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
4th November 1925	0—6″	25·2	·00079	11·87	24·1	·0011	16·63
	6—12″	25·1	·00073	10·94	25·1	·00055	8·20
	12—18″	25·4	·00055	8·23	26·2	·00055	8·29
	18—24″	28·3	·00056	8·47	26·7	·00068	10·16
	24—30″	30·2	·00051	7·67	28·7	·00069	10·39
	30—36″	30·9	·00045	6·75	28·4	·00056	8·48
				53·93			62·15
17th November 1925	0—6″	32·4	·00065	9·78	31·2	·00077	11·61
	6—12″	32·2	·00052	7·81	29·3	·00076	11·40
	12—18″	29·1	·00044	6·64	25·4	·00061	9·14
	18—24″	26·6	·00037	5·55	25·9	·00049	7·35
	24—30″	29·3	·00038	5·70	30·9	·00045	6·75
	30—36″	29·6	·00038	5·72	29·9	·00045	6·69
				41·20			52·94
25th November 1925	0—6″	32·9	·00059	8·84	31·9	·00071	10·71
	6—12″	34·2	·00046	6·96	30·0	·00057	8·61
	12—18″	32·9	·00046	6·87	30·4	·00045	6·72
	18—24″	29·5	·00038	5·71	29·4	·00038	5·71
	24—30″	31·3	·00039	5·81	32·8	·00046	6·87
	30—36″	31·6	·00039	5·82	32·3	·00046	6·84
				40·01			45·46
2nd December 1925	0—6″	28·5	·00050	7·55	28·4	·00056	8·48
	6—12″	29·4	·00044	6·65	29·8	·00051	7·64
	12—18″	28·4	·00044	6·59	30·3	·00077	11·51
	18—24″	29·6	·00051	7·63	29·9	·00051	7·64
	24—30″	29·4	·00051	7·61	32·9	·00059	8·85
	30—36″	31·3	·00045	6·78	33·8	·00053	7·93
				42·81			52·05
12th December 1925	0—6″	27·4	·00043	6·53	27·4	·00075	11·19
	6—12″	28·3	·00038	5·65	26·5	·00062	9·24
	12—18″	30·4	·00038	5·76	29·5	·00044	6·66
	18—24″	30·1	·00032	4·78	27·2	·00037	5·58
	24—30″	31·6	·00045	6·80	28·8	·00038	5·67
	30—36″	33·1	·00039	5·90	28·9	·00038	5·68
				35·42			44·02

TABLE I. PERIOD (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926—contd.

Date	Depth	Unmanured plot: % Water on dry soil	Unmanured plot: $NaNO_3$ in dry soil: Grm. per 100 grm.	Unmanured plot: $NaNO_3$ in dry soil: Lb. per acre	Manured plot: % Water on dry soil	Manured plot: $NaNO_3$ in dry soil: Grm. per 100 grm.	Manured plot: $NaNO_3$ in dry soil: Lb. per acre
16th December 1925	0—6″	28·1	·00044	6·58	26·6	·00062	9·26
	6—12″	23·2	·00044	6·58	26·4	·00049	7·39
	12—18″	28·7	·00044	6·61	25·5	·00043	6·40
	18—24″	30·9	·00045	6·75	30·2	·00045	6·71
	24—30″	30·8	·00051	7·71	28·3	·00050	7·55
	30—36″	32·5	·00052	7·83	29·8	·00044	6·67
				42·06			43·98
23rd December 1925	0—6″	23·8	·00048	7·20	25·4	·00055	8·25
	6—12″	26·4	·00043	6·47	25·5	·00049	7·32
	12—18″	27·7	·00037	5·61	27·2	·00043	6·52
	18—24″	30·0	·00038	5·74	27·8	·00044	6·56
	24—30″	32·4	·00046	6·85	25·4	·00043	6·40
	30—36″	31·0	·00039	5·79	27·1	·00043	6·51
				37·66			41·54
28th December 1925	0—6″	27·2	·00050	7·45	24·7	·00061	9·08
	6—12″	27·5	·00044	6·54	24·0	·00054	8·12
	12—18″	29·0	·00044	6·63	24·9	·00055	8·19
	18—24″	30·8	·00045	6·75	26·2	·00055	8·20
	24—30″	29·4	·00038	5·70	26·5	·00049	7·39
	30—36″	32·1	·00039	5·85	29·3	·00051	7·60
				38·92			48·68
6th January 1926	0—6″	25·9	·00086	12·87	26·6	·00093	13·88
	6—12″	26·9	·00080	12·07	27·8	·0011	16·86
	12—18″	27·6	·00062	9·35	27·3	·00099	14·90
	18—24″	30·2	·00064	9·58	26·3	·00086	12·91
	24—30″	31·1	·00064	9·66	27·3	·00068	10·25
	30—36″	30·4	·00064	9·60	27·2	·00068	10·24
				63·13			79·04
16th January 1926	0—6″	30·0	·0015	22·91	31·0	·0017	25·10
	6—12″	27·9	·0010	15·00	28·9	·0011	17·04
	12—18″	26·9	·0011	16·70	28·0	·0010	15·01
	18—24″	27·7	·0010	14·96	31·5	·00078	11·64
	24—30″	29·3	·0010	15·21	28·6	·00076	11·33
	30—36″	29·3	·0010	15·21	29·0	·00088	13·26
				99·99			93·38

TABLE I. PERIOD (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926—contd.

Date	Depth	Unmanured plot			Manured plot		
		%Water on dry soil	$NaNO_3$ in dry soil		%Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
21st January 1926 .	0—6″	23·4	·00084	12·54	24·9	·0013	20·03
	6—12″	22·3	·00074	11·17	23·2	·00057	8·53
	12—18″	21·0	·00082	12·15	23·6	·00084	12·58
	18—24″	23·1	·00083	12·51	23·0	·00071	10·71
	24—30″	26·5	·00062	9·24	25·5	·00061	9·15
	30—36″	26·2	·00074	11·07	24·2	·00060	9·04
				68·68			70·04
28th January 1926 .	0—6″	24·9	·00069	9·10	25·3	·00097	14·62
	6—12″	27·1	·00037	5·58	25·3	·00073	10·99
	12—18″	26·4	·00062	9·24	26·7	·00062	9·26
	18—24″	27·2	·00031	4·65	29·6	·00063	9·51
	24—30″	30·7	·00064	9·63	27·2	·00062	9·31
	30—36″	31·8	·00098	14·76	27·6	·00050	7·47
				52·96			61·16
3rd February 1926 .	0—6″	26·6	·00099	14·80	27·4	·0010	15·85
	6—12″	24·6	·00078	11·72	25·7	·00098	14·68
	12—18″	28·7	·00076	11·34	26·6	·00086	12·95
	18—24″	28·1	·00069	10·33	25·7	·00086	12·85
	24—30″	31·2	·00071	10·65	30·5	·00077	11·53
	30—36″	31·7	·00071	10·70	29·5	·00076	11·43
				69·54			99·29
12th February 1926 .	0—6″	25·6	·0010	15·57	24·2	·00096	14·46
	6—12″	23·8	·0013	18·89	23·3	·0014	21·49
	12—18″	24·6	·00091	13·61	23·5	·00090	13·47
	18—24″	22·9	·00095	14·26	22·3	·0010	15·07
	24—30″	23·4	·00095	14·33	26·4	·00092	15·84
	30—36″	24·1	·00084	12·64	23·5	·00078	11·67
				89·30			90·00
20th February 1926 .	0—6″	22·1	·00077	11·50	21·9	·00088	13·23
	6—12″	21·6	·00076	11·43	21·9	·0011	15·88
	12—18″	20·7	·00093	13·96	20·5	·0010	15·65
	18—24″	23·1	·00089	13·40	23·4	·0010	15·22
	24—30″	25·2	·00079	11·86	24·0	·0010	15·34
	30—36″	26·4	·00074	11·98	24·9	·00085	12·74
				73·23			88·06

TABLE I. PERIOD (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926—contd.

Date	Depth	UNMANURED PLOT			MANURED PLOT		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
25th February 1926 .	0—6″	23·5	·00072	10·78	23·1	·00077	11·62
	6—12″	23·4	·00072	10·75	21·9	·00071	10·59
	12—18″	24·4	·00091	13·59	23·1	·00071	10·71
	18—24″	24·0	·00084	12·62	23·4	·00084	12·54
	24—30″	28·1	·00075	11·26	27·9	·00076	11·43
	30—36″	30·1	·00089	13·41	26·0	·00086	12·87
				72·41			69·76
4th March 1926 .	0—6″	23·2	·00066	9·84	22·7	·00053	8·01
	6—12″	24·9	·00067	10·01	22·1	·00059	8·84
	12—18″	24·9	·00067	10·01	22·9	·00053	8·03
	18—24″	24·2	·00078	11·75	22·1	·00047	7·07
	24—30″	26·2	·00074	11·06	24·4	·00054	8·15
	30—36″	26·4	·00068	10·16	27·4	·00056	8·38
				62·83			48·48
10th March 1926 .	0—6″	24·9	·00079	11·83	21·2	·00070	10·53
	6—12″	23·1	·00054	8·04	22·2	·00077	11·51
	12—18″	22·7	·00053	8·01	23·2	·00072	10·74
	18—24″	25·2	·00061	9·12	22·1	·00059	8·85
	24—30″	28·0	·00069	10·32	25·2	·00060	9·94
	30—36″	30·8	·00077	11·56	26·4	·00062	9·24
				58·88			60·01
18th March 1926 .	0—6″	22·1	·00077	11·50	19·3	·0011	17·19
	6—12″	23·9	·00060	9·01	21·5	·0011	16·70
	12—18″	23·6	·00060	8·98	23·2	·00077	11·63
	18—24″	26·4	·00062	9·23	22·7	·00059	8·90
	24—30″	28·2	·00063	9·40	23·9	·00060	9·01
	30—36″	31·4	·00065	9·69	23·5	·00078	11·65
				57·81			75·08
25th March 1926 .	0—6″	17·2	·00084	12·59	22·5	·00083	12·42
	6—12″	22·3	·00059	8·86	22·1	·00094	14·14
	12—18″	22·7	·00059	8·90	23·5	·00084	12·55
	18—24″	24·0	·00060	9·92	24·1	·00096	14·44
	24—30″	26·7	·00062	9·26	26·5	·00062	9·25
	30—36″	27·4	·00062	9·33	25·2	·00073	10·95
				57·96			73·75

TABLE I. PERIOD (*a*).

Showing nitrate and moisture content of soil throughout the year, 21st June 1925—8th April 1926—concld.

Date	Depth	Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: Lb. per acre	% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: Lb. per acre
31st March 1926	0—6″	10·2	·0013	26·19	12·9	·0015	22·42
	6—12″	22·0	·00076	11·45	21·2	·0010	15·78
	12—18″	24·6	·00060	9·07	23·2	·0011	16·09
	18—24″	24·4	·00060	9·06	23·8	·00084	12·59
	24—30″	28·0	·00069	10·32	25·6	·00085	12·82
	30—36″	28·0	·00075	11·25	25·9	·00067	10·11
				71·34			89·81
8th April 1926	0—6″	10·5	·0013	20·25	9·3	·0025	36·88
	6—12″	21·9	·00053	7·95	19·2	·00091	13·72
	12—18″	23·6	·00042	6·29	22·0	·00053	7·95
	18—24″	22·5	·00047	7·10	23·5	·00054	8·08
	24—30″	25·6	·00055	8·24	24·0	·00054	8·12
	30—36″	27·6	·00056	8·41	26·3	·00055	8·30
				58·24			83·05

The above figures are expressed in diagrammatic form in Chart I. It will be seen that when the experiment was first started the soil already contained an appreciable quantity of nitrate. This is obviously due to the fact that several inches of rain had already fallen. A comparison of the moisture content of the samples taken on 21st June 1925 with those taken at the beginning of the hot weather on 8th April 1926, *i.e.*, when the soil had been drying out for several months shows that the moisture in the lower depths was similar on both occasions. The rainfall up to 21st June 1925 had therefore only affected the moisture content of the top 6″ of soil and it is in this top 6″ that the greatest increase of nitrate has taken place. In the case of the unmanured plot there was no nitrate at all in the 3rd foot of soil but the manured plot contained nitrate at each depth sampled. The manured plot is seen to contain much more nitrate than the unmanured plot. Before the second sample was taken on 25th June 1925, a further 2-3″ of rain had fallen and this was sufficient to increase considerably the moisture at lower depths. This extra rainfall also largely increased nitrification and both plots contained at this time their maximum nitrate content.

The drains under the plots did not start flowing until 8th July. The drains are laid at a depth of 2′-6″ and on 8th July when they first started running the layer 2′—2′·6″ deep held 32·5 and 34·4 per cent. of moisture in the manured and unmanured plots respectively. On the 1st July these same layers held 30·1 and 29·8 per cent. of moisture respectively and apparently drainage does not take place until this figure is exceeded. Although the drains did not flow until July 8th, yet a consideration of the analyses made on 25th June and 1st July shows that the moisture was steadily moving downwards taking with it the nitrate formed at the surface.

The drains ran practically continuously throughout July and the heavy rains between 7th and 13th July very largely depleted the nitrate stores in the soil. In the second half of July only a light sprinkling of rain was received. Nitrates again accumulated in the surface 6″ layer of both plots. On the 29th and 30th there was a fall of about 5″ of rain and the samples of 30th July were taken after this. It will be seen that the soil lost nearly all its nitrate. There appeared to be some increase in nitrates in the samples taken on the 13th August, but in general from this date onwards no further accumulation of nitrate took place in the soil. By October the surface soil had dried considerably. On October 15th a fall of 1½″ rain occurred and there were further light falls on 20th and 28th October. An appreciable increase in the soil nitrate especially in the surface 6″ occurred as a result of these falls of rain. The chart will show other cases where a light fall of rain was followed subsequently by an increase in soil nitrate, *e.g.* the rainfall at the beginning of January is obviously connected with the nitrate increase in the samples taken on 16th January and subsequent dates and the increase in nitrate at the end of March and in April is also connected with the light rainfall received just previously.

Conclusion.

A consideration of the above results brings forth several definite points :

(1) Shortly after the onset of the rains nitrification becomes very active. The maximum amount of nitrate in the top 3 feet of soil was found on 25th June after about 6″ of rain had fallen. The unmanured and manured plots contained nitrate nitrogen equivalent to 240 lb. and 340 lb. nitrate of soda per acre in the top 3 feet respectively. Since the crop was sown on 19th June the presence of such large stores of nitrate in the soil at this particular time appears to be useless to the crop especially as only 30—40 lb. of it is present in the top 6″. If the crop could be sown earlier so that the plants are large enough to take advantage of the large stores of nitrate present at this time it would be of great advantage but unfortunately moisture conditions in the soil are rarely favourable for the very early sowing which would be necessary to enable the crop to develop in time to profit by the large stores of nitrate produced early in the rains.

(2) The effect of a heavy fall of rain in depleting the nitrate found in the soil is well seen in the Chart. Top-dressing with nitrates should obviously be done immediately after such heavy falls, as the growing crop is likely to be short of nitrate for some time after they occur.

(3) There appears to be a large loss of nitrate from the top 3 feet of soil during the rains. One can compute from Table I roughly the amount of nitrate of soda which is lost from the soil presumably by drainage during the duration of the experiment. The figures are roughly 480 and 620 lb. of nitrate of soda per acre for the unmanured and manured plots respectively. These figures have been obtained by noting the first maximum amount of nitrate found, *viz.*, on 25th June there were 240 and 340 lb. nitrate of soda present per acre in the top 3 feet of soil. On the 15th July these amounts had diminished to 131 and 169 lb. nitrate of soda a loss of 109 and 171 lb. respectively. On 22nd July the nitrate had increased to 188 and 284 lb. respectively and had diminished to 69 and 94 lb. by 3rd August a further loss of 119 and 190 lb. respectively. Proceeding in this way the total loss of nitrate of soda per acre from the unmanured and manured plots is found to be roughly 480 and 620 lb., respectively.

The results for the period (*b*), *viz.*, 16th April 1926 and 28th October 1926, are set out in Table II. This table is set out in the same manner as Table I but as explained previously four plots were under experiment during this period.

TABLE II,

Showing nitrate and moisture content of soil throughout

Date	Depth	UNCROPPED AREA					
		UNMANURED PLOT			MANURED PLOT		
		% Water on dry soil	$NaNO_3$ in dry soil Grm. per 100 grm.	$NaNO_3$ in dry soil lb. per acre	% Water on dry soil	$NaNO_3$ in dry soil Grm. per 100 grm.	$NaNO_3$ in dry soil lb. per acre
16th April 1926	0—6	6·9	·0012	17·89	8·5	·00076	11·34
	6—12	18·8	·00068	10·25	20·8	·00035	5·24
	12—18	23·2	·00030	4·47	23·0	·00024	3·57
	18—24	23·8	·00030	4·50	25·2	·00024	3·65
	24—30	24·4	·00030	4·53	26·2	·00018	2·77
	30—36	24·4	·00030	4·53	28·4	·00031	4·71
				46·17			31·28
30th April 1926	0—6	9·5	·00067	10·01	10·6	·00059	8·92
	6—12	23·6	·00042	6·28	21·4	·00024	3·57
	12—18	27·4	·00034	5·15	29·2	·00015	2·27
	18—24	30·2	·00032	4·79	28·4	·00019	2·86
	24—30	34·4	·00033	4·98	27·1	·00023	3·45
	30—36	28·4	·00031	4·71	27·6	·00027	4·01
				35·92			25·08
13th May 1926	0—6	9·1	·0010	15·31	10·0	·0010	15·48
	6—12	19·5	·00057	8·61	20·0	·00069	10·38
	12—18	23·0	·00048	7·14	24·9	·00036	5·46
	18—24	28·2	·00050	7·52	28·7	·00050	7·56
	24—30	30·6	·00038	5·77	28·2	·00044	6·58
	30—36	30·6	·00045	6·73	30·1	·00032	4·79
				51·08			50·25
21st May 1926	0—6	29·2	·0025	22·77	32·4	·0014	21·52
	6—12	26·8	·0033	50·07	31·3	·0015	23·25
	12—18	26·6	·00055	8·33	28·8	·00050	7·57
	18—24	28·2	·00057	8·52	27·4	·00050	7·46
	24—30	27·0	·00056	8·36	26·2	·00049	7·37
	30—36	26·1	·00055	8·29	27·9	·00050	7·50
				106·34			74·67
24th May 1926	0—6	25·6	·0026	38·47	27·6	·0035	51·30
	6—12	17·2	·00095	14·26	25·6	·0016	24·73
	12—18	21·1	·00064	9·83	22·8	·00095	14·26
	18—24	24·9	·00073	10·92	25·5	·00061	9·15
	24—30	28·3	·00063	9·41	30·6	·00064	9·61
	30—36	30·9	·00064	9·64	27·4	·00062	9·33
				92·53			119·38

PERIOD (*b*).

the period 16th April—28th October 1926.

CROPPED AREA

Unmanured plot			Manured plot		
% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: lb. per acre	% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: lb. per acre
8·5	·0012	18·24	7·1	·0014	20·94
21·0	·00047	7·0	17·3	·00078	11·77
24·5	·00042	6·34	20·8	·00058	8·72
30·1	·00038	5·78	23·10	·00054	8·03
31·9	·00039	5·88	24·9	·00030	4·55
33·4	·00040	5·96	26·5	·00025	3·70
		49·19			57·71
10·4	·00063	9·39	7·6	·0010	15·03
21·9	·00053	7·97	19·0	·00057	8·56
25·7	·00036	5·48	25·2	·00061	9·13
26·6	·00036	5·47	27·6	·00056	8·41
29·9	·00038	5·71	30·1	·00038	5·75
28·4	·00044	6·67	28·0	·00030	4·47
		40·69			51·35
11·4	·0010	15·73	9·1	·0011	16·84
17·8	·00056	8·45	15·0	·00096	11·47
24·7	·00042	6·35	21·3	·00058	8·77
25·1	·00043	6·38	29·9	·00051	7·64
23·3	·00036	5·37	24·7	·00048	7·26
25·2	·00036	5·47	25·2	·00043	6·38
		47·75			58·36
32·6	·0012	17·64	32·5	·002	29·35
30·9	·0015	23·14	21·2	.0012	17·52
28·5	·00075	11·32	26·1	·0011	16·56
29·1	·00076	11·39	26·8	·00099	14·83
30·5	·00058	8·65	27·1	·00050	7·44
30·4	·00058	8·64	28·5	·00063	9·44
		80·78			95·14
26·8	·0026	38·94	26·1	·0032	47·82
20·8	·00099	14·84	16·4	·0013	19·98
22·9	·00089	13·38	23·1	·00083	12·51
24·4	·00066	9·95	24·1	·00066	9·93
26·5	·00062	9·25	28·3	·00069	10·36
27·0	·00068	10·22	25·0	·00085	12·75
		96·58			113·35

TABLE II,

Showing nitrate and moisture content of soil throughout

Date	Depth	UNCROPPED AREA					
		UNMANURED PLOT			MANURED PLOT		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	lb. per acre		Grm. per 100 grm.	lb. per acre
1st June 1926	0— 6	20·0	·0028	41·56	20·8	·0028	41·94
	6—12	17·5	·00084	12·64	21·0	·0016	24·49
	12—18	24·1	·00090	13·54	24·9	·00085	12·75
	18—24	25·1	·00061	9·12	26·4	·00074	11·08
	24—30	27·9	·00062	9·37	29·8	·00045	6·68
	30—36	25·5	·00043	6·40	29·0	·00051	7·59
				92·63			104·53
4th June 1926	0— 6	17·3	·0028	42·03	14·4	·0026	39·09
	6—12	17·6	·00056	8·44	17·7	·00067	10·13
	12—18	21·9	·00059	8·82	22·2	·00059	8·86
	18—24	22·2	·0010	15·04	22·8	·00095	14·26
	24—30	28·5	·00058	7·54	25·7	·00067	10·08
	30—36	28·8	·00044	6·62	22·8	·00065	9·79
				88·49			92·21
9th June 1926	0— 6	12·8	·0019	28·81	13·6	·0028	41·94
	6—12	14·9	·0014	21·28	10·6	·0011	17·16
	12—18	21·2	·00070	10·52	19·7	·00092	13·80
	18—24	21·9	·00065	9·71	19·5	·00092	13·78
	24—30	28·4	·00050	7·53	20·2	·00069	10·40
	30—36	28·1	·00050	7·51	21·1	·00059	8·84
				85·36			105·92
16th June 1926	0— 6	17·8	·0025	37·18	18·3	·0045	67·98
	6—12	24·0	·00066	9·92	24·0	·0029	43·32
	12—18	25·2	·00049	7·30	27·0	·0010	15·78
	18—24	28·2	·00069	10·35	29·3	·0015	15·21
	24—30	26·0	·00043	6·44	21·1	·00058	8·69
	30—36	28·6	·00044	6·61	29·4	·00051	7·61
				77·80			158·59
21st June 1926	0— 6	15·3	·0031	46·03	16·4	·0035	53·29
	6—12	24·4	·0014	21·73	24·9	·0021	30·94
	12—18	29·2	·00051	7·59	28·5	·0016	24·51
	18—24	29·1	·00057	8·53	31·1	·0012	17·38
	24—30	30·7	·00058	8·66	29·6	·00063	9·53
	30—36	28·1	·00056	8·45	26·0	·00074	11·04
				100·99			146·69

PERIOD (*b*)—*contd.*

the period 16th April—28th October 1926—contd.

CROPPED AREA

Unmanured plot			Manured plot		
% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
	Grm. per 100 grm.	lb. per acre		Grm. per 100 grm.	lb. per acre
18·1	·0024	35·62	21·2	·0050	71·82
21·8	·00071	10·58	18·1	·0015	22·05
24·9	·00091	13·65	23·8	·0011	16·20
26·7	·00093	13·90	22·9	·00095	14·27
27·8	·00044	6·56	28·1	·00056	8·44
28·7	·00057	8·50	26·0	·00067	10·12
		88·81			142·90
14·7	·0023	34·32	12·6	·0017	25·54
18·6	·00074	11·09	18·0	·00090	13·56
23·6	·00054	8·09	21·0	·00058	8·74
21·8	·00047	7·05	22·9	·00059	8·92
26·8	·00049	7·42	24·7	·00054	8·17
25·2	·00091	13·68	24·0	·00054	8·11
		81·65			73·04
16·2	·0031	46·50	11·9	·0033	49·06
18·1	·0016	23·76	14·3	·0015	21·96
21·1	·00088	13·26	24·0	·00066	9·92
26·5	·00080	12·01	25·5	·00061	9·14
29·0	·00076	11·37	24·7	·00042	6·36
29·8	·00051	7·63	25·8	·00055	8·27
		114·53			104·71
21·0	·0026	38·49	20·8	·0045	68·13
25·2	·00097	14·59	27·4	·0019	27·99
26·6	·00049	7·40	27·7	·00081	12·16
27·6	·00037	5·61	27·4	·00050	7·46
27·7	·00031	4·68	30·1	·00045	6·70
28·3	·00031	4·70	28·3	·00050	7·53
		75·47			129·97
12·5	·0026	38·25	16·7	·0058	86·79
20·3	·0016	24·31	22·9	·0021	32·13
23·5	·00090	13·45	28·2	·0010	15·03
25·2	·00091	13·67	25·8	·00079	11·93
28·6	·00050	7·55	30·1	·00070	10·53
29·6	·00051	7·63	30·9	·00064	9·64
		104·86			166·05

TABLE II,

Showing nitrate and moisture content of soil throughout

Date	Depth	UNCROPPED AREA — Unmanured plot: % Water on dry soil	Unmanured plot: $NaNO_3$ in dry soil, Grm. per 100 grm.	Unmanured plot: $NaNO_3$ in dry soil, lb. per acre	Manured plot: % Water on dry soil	Manured plot: $NaNO_3$ in dry soil, Grm. per 100 grm.	Manured plot: $NaNO_3$ in dry soil, lb. per acre
30th June 1926	0—6	11·8	·0033	49·02	12·3	·0047	70·00
	6—12	19·2	·0013	18·87	17·8	·0013	20·29
	12—18	23·4	·00048	7·16	21·1	·00058	8·75
	18—24	25·2	·00091	13·69	20·4	·0015	22·57
	24—30	24·4	·00042	6·34	22·9	·00059	8·92
	30—36	23·4	·00060	8·96	23·9	·00060	9·01
				104·04			139·54
9th July 1926	0—6	39·0	·0014	20·77	39·0	·0018	27·01
	6—12	36·9	·0022	32·61	37·9	·0016	24·66
	12—18	37·9	·0023	34·96	35·0	·0023	34·05
	18—24	38·7	·0021	31·06	36·8	·0020	30·54
	24—30	39·5	·0012	18·76	41·4	·0018	27·58
	30—36	40·8	·00091	13·71	38·4	·0015	22·71
				151·87			166·55
14th July 1926	0—6	39·5	·00097	14·59	39·2	·0014	21·84
	6—12	35·5	·00080	12·07	38·2	·0014	20·62
	12—18	37·1	·00082	12·25	39·0	·0023	35·29
	18—24	40·1	·0010	15·72	38·1	·0029	43·27
	24—30	38·5	·0019	28·96	40·5	·0028	42·07
	30—36	42·4	·0018	26·73	40·6	·0023	34·75
				110·32			197·84
19th July 1926	0—6	33·2	·0012	17·73	36·8	·0027	40·90
	6—12	33·4	·0010	15·78	33·0	·0018	27·54
	12—18	36·2	·00076	11·35	33·9	·0020	29·76
	18—24	39·4	·00083	12·51	40·4	·0023	35·74
	24—30	34·0	·00079	11·92	38·7	·0032	47·62
	30—36	35·3	·00067	10·05	39·0	·0028	41·50
				79·34			223·06
24th July 1926	0—6	31·5	·0016	24·39	33·2	·0034	51·21
	6—12	31·9	·0011	16·56	34·5	·0019	28·93
	12—18	34·3	·00066	9·95	34·5	·0018	26·94
	18—24	33·9	·00079	11·90	36·4	·0016	24·36
	24—30	32·8	·00098	14·73	40·1	·0017	25·32
	30—36	33·3	·00099	14·80	37·9	·0014	20·92
				92·33			177·68

PERIOD (*b*)—*contd*

the period 16th April—28th October 1926—contd.

CROPPED AREA

Unmanured plot			Manured plot		
% water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
	Grm. per 100 grm.	lb. per acre		Grm. per 100 grm.	lb. per acre
11·2	·0027	40·84	12·0	·0054	80·86
18·4	·0016	23·82	18·5	·0020	30·66
23·3	·00060	8·95	24·0	·00060	9·01
26·0	·00067	10·12	24·9	·00061	9·10
25·7	·00049	7·33	27·0	·00043	6·50
25·7	·00049	7·33	27·4	·00037	5·60
		98·39			141·74
38·7	·0011	16·57	40·1	·0018	27·25
35·3	·0023	34·17	35·8	·0025	38·37
33·9	·0028	41·67	37·5	·0034	50·53
32·5	·0027	41·11	36·4	·0019	28·39
35·1	·0012	18·06	38·1	·0018	26·77
36·0	·0012	18·19	37·4	·0018	26·61
		169·77			197·92
38·4	·00083	12·39	39·4	·0017	25·00
36·2	·0010	15·21	35·1	·0013	20·27
32·4	·00065	9·79	35·6	·00094	14·09
38·8	·00062	9·32	36·5	·0015	23·38
42·4	·0011	16·05	37·6	·00075	11·29
41·3	·0012	18·76	40·8	·0020	30·55
		81·52			124·38
32·8	·0014	21·60	33·3	·0020	29·59
32·7	·00099	14·90	33·3	·0014	21·70
33·2	·00078	11·82	33·8	·00092	13·87
35·2	·00080	12·06	34·9	·0013	20·02
40·1	·0011	16·77	38·8	·0015	22·80
38·3	·0018	26·82	39·2	·0012	18·73
		103·97			126·71
32·8	·0016	23·56	30·7	·0043	63·97
31·9	·0011	16·56	34·1	·0013	19·86
32·8	·00079	17·91	34·2	·00093	13·92
35·1	·00080	12·04	35·3	·0017	26·19
36·9	·0010	15·30	38·1	·0015	22·65
38·7	·0012	17·61	36·8	·0014	20·35
		102·98			166·94

TABLE II,

Showing nitrate and moisture content of soil throughout

Date	Depth	UNCROPPED AREA					
		UNMANURED PLOT			MANURED PLOT		
		% Water on dry soil	NaNO$_3$ in dry soil Grm. per 100 grm.	NaNO$_3$ in dry soil lb. per acre	% Water in dry soil	NaNO$_3$ in dry soil Grm. per 100 grm.	NaNO$_3$ in dry soil lb. per acre
29th July 1926	0— 6	31·6	·0026	39·82	34·3	·0033	49·81
	6—12	31·9	·0016	24·34	32·4	·0031	46·93
	12—18	31·9	·0014	21·48	31·3	·0030	44·55
	18—24	35·1	·00073	10·32	34·8	·0028	42·01
	24—30	33·2	·0010	15·76	37·1	·0022	32·68
	30—36	31·3	·00090	13·55	37·8	·0021	31·83
				125·27			247·81
9th August 1926	0— 6	39·5	·0012	18·76	38·4	·0012	18·61
	6—12	37·6	·0012	18·47	34·7	·0010	15·00
	12—18	36·4	·0010	15·21	36·8	·00095	14·25
	18—24	35·3	·0010	15·57	38·6	·0012	18·64
	24—30	33·6	·00086	12·85	39·6	·0014	20·89
	30—36	35·5	·00087	13·08	38·4	·0014	20·64
				93·94			108·03
14th August 1926.	0— 6	38·9	·00097	14·52	41·2	·0011	16·96
	6—12	36·1	·00094	14·15	39·6	·0011	16·41
	12—18	35·6	·0011	16·11	38·9	·0010	15·55
	18—24	37·6	·0010	15·42	38·8	·0012	17·61
	24—30	39·5	·0012	18·76	41·5	·0014	21·24
	30—36	38·9	·0012	18·68	40·5	·0017	26·28
				97·64			114·05
19th August 1926.	0— 6	40·7	·00084	12·65	39·9	·00091	13·60
	6—12	35·1	·00080	12·04	39·5	·00090	13·55
	12—18	35·7	·00067	10·08	37·4	·00082	12·28
	18—24	39·1	·00069	10·39	40·1	·00084	12·57
	24—30	40·3	·00063	9·44	41·6	·00099	14·89
	30—36	37·6	·00082	12·31	43·1	·0014	20·43
				66·91			87·32
24th August 1926.	0— 6	38·2	·0012	17·50	39·0	·0011	16·59
	6—12	34·9	·00080	12·01	37·1	·00095	14·30
	12—18	37·9	·00068	10·28	37·6	·00075	11·29
	18—24	37·8	·00068	10·27	39·3	·00069	10·41
	24—30	40·1	·00070	10·47	39·6	·0011	16·71
	30—36	37·0	·00068	10·19	39·0	·0017	25·95
				70·72			95·25

PERIOD (*b*)—*contd.*

the period 16th April—28th October 1926—contd.

CROPPED AREA					
UNMANURED PLOT			MANURED PLOT		
%Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: lb. per acre	% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: lb. per acre
32·1	·0030	44·85	32·2	·0027	40·99
30·0	·0017	24·88	31·9	·0022	33·12
32·5	·00098	14·68	31·8	·0022	33·06
33·3	·0014	21·69	31·6	·0019	29·14
33·3	·0016	23·67	34·2	·0019	28·84
31·8	·0015	23·32	35·1	·0019	29·08
		153·09			194·23
38·1	·00082	12·36	41·2	·0013	19·06
34·7	·00080	12·00	39·0	·0014	20·77
35·3	·00080	12·05	36·4	·0012	18·25
36·4	·00068	10·14	37·0	·0010	15·31
37·5	·00096	14·34	37·8	·0014	20·55
38·4	·00089	13·42	38·9	·0014	20·74
		74·31			114·68
37·6	·0011	16·41	39·0	·0013	19·74
34·3	·0011	15·92	37·1	·0011	16·34
35·1	·0010	15·02	35·8	·0010	15·68
36·4	·00088	13·18	36·4	·0010	15·21
37·1	00088	13·28	39·2	·0011	16·62
37·5	·00096	14·35	39·3	·0014	20·82
		88·16			103·81
37·6	·00055	8·21	41·6	·0011	15·96
36·4	·00054	8·11	37·4	·00095	14·33
33·1	·00052	7·86	37·1	·00082	12·21
34·7	·00067	9·99	35·5	·00074	11·07
33·6	·00059	8·89	35·4	·00094	14·07
35·1	·00067	10·01	37·6	·00089	13·34
		53·07			80·98
35·5	·00080	12·08	39·9	·00091	13·60
33·3	·00085	12·82	37·0	·00082	12·21
33·4	·00072	10·85	36·1	·00067	10·11
33·6	·00059	8·90	34·9	·00067	10·01
38·0	·00068	10·28	37·8	·0015	22·60
37·1	·00075	11·24	37·5	·0016	24·62
		66·17			93·15

TABLE II,

Showing nitrate and moisture content of soil throughout

Date	Depth	UNCROPPED AREA					
		UNMANURED PLOT			MANURED PLOT		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	lb. per acre		Grm. per 100 grm.	lb. per acre
2nd September 1926.	0—6	38·1	·00082	12·36	40·5	·00098	14.72
	6—12	36·3	·00068	10·14	36·8	·00075	11·19
	12—18	38·7	·00069	10·35	37·3	·00061	9·21
	18—24	39·7	·00070	10·47	37·6	·00068	10·26
	24—30	36·9	·00054	8·14	38·8	·00069	10·37
	30—36	36·2	·00067	10·12	37·9	·00062	9·25
				61·58			65·00
8th September 1926.	0—6	37·4	·00095	14·33	37·3	·0010	15·33
	6—12	34·1	·00079	11·92	36·5	·00081	12·19
	12—18	34·6	·00073	10·97	34·8	·00067	9·99
	18—24	37·4	·00061	9·21	35·1	·00067	10·03
	24—30	39·9	·00056	8·37	41·4	·00071	10·62
	30—36	37·1	·00075	11·24	41·8	·00085	12·78
				66·04			70·94
16th September 1926.	0—6	34·4	·00093	13·95	36·4	·0020	30·42
	6—12	32·3	·00071	10·72	33·0	·0010	15·72
	12—18	34·1	·00053	7·94	33·4	·00053	7·90
	18—24	36·0	·00054	8·09	34·7	·00053	7·99
	24—30	39·9	·00063	9·46	37·9	·00062	9·24
	30—36	39·5	·00076	11·46	38·1	·00069	10·29
				61·62			81·56
22nd September 1926.	0—6	34·7	·0021	31·02	35·8	·0024	35·34
	6—12	31·6	·00071	10·66	34·4	·0010	14·94
	12—18	34·1	·00060	8·94	34·4	·00071	10·60
	18—24	35·6	·00074	11·08	33·6	·00053	7·90
	24—30	39·8	·00056	8·35	39·9	·00077	11·51
	30—36	40·7	·00070	10·54	38·3	·0014	21·67
				80·59			101·96
28th September 1926.	0—6	32·8	·00078	11·76	33·9	·0011	15·84
	6—12	32·5	·00046	6·84	32·8	·00052	7·84
	12—18	33·9	·00040	5·94	34·1	·00046	6·95
	18—24	36·4	·00034	5·07	33·5	·00053	7·90
	24—30	37·9	·00048	7·20	37·3	·00041	6·14
	30—36	41·0	·00070	10·58	40·6	·00056	8·44
				47·39			53·11

PERIOD (*b*)—*contd.*

the period 16th April—28th October 1926—contd.

CROPPED AREA					
UNMANURED PLOT			MANURED PLOT		
% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: lb. per acre	% Water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: lb. per acre
36·3	·00088	13·16	39·8	·0011	16·74
33·5	·00079	11·85	36·2	·00094	14·17
35·4	·00067	10·06	37·1	·00075	11·21
32·2	·00071	10·73	35·8	·00060	9·07
37·4	·00068	10·24	39·5	·00069	10·42
39·8	·00077	11·52	40·9	·00070	10·56
		67·56			72·17
34·6	·00080	11·97	39·1	·00097	14·52
32·3	·00065	9·75	33·7	·00066	9·89
34·8	·00067	9·99	35·2	·00067	10·03
33·2	·00066	9·84	35·8	·00054	8·08
36·2	·00054	8·10	37·6	·00055	8·21
36·9	·00061	9·17	37·4	·00055	8·21
		58·82			58·94
34·1	·00066	9·93	35·6	·00094	14·11
32·0	·00052	7·78	34·4	·00066	9·96
31·9	·00052	7·78	33·6	·00053	7·90
32·5	·00046	6·84	35·8	·00040	6·06
36·2	·00047	7·08	37·1	·00041	6·13
37·9	·00048	7·19	39·2	·00069	10·41
		46·60			54·57
33·6	·00066	9·87	37·0	·0014	20·40
32·1	·00052	7·79	35·0	·00087	13·02
33·1	·00059	8·86	33·7	·00079	11·86
37·0	·00048	7·14	35·3	·00060	9·04
35·4	·00047	7·03	40·1	·00056	8·38
35·6	·00054	8·05	40·1	·00056	8·37
		48·74			71·07
31·2	·00039	5·80	30·9	·00064	9·64
31·3	·00039	5·80	31·9	·00052	7·78
33·5	·00033	4·93	32·5	·00039	5·85
33·5	·00026	3·95	32·2	·00032	4·87
34·2	·00026	3·98	38·7	·00028	4·14
36·6	·00027	4·06	37·7	·00027	4·11
		28·52			36·39

TABLE II,

Showing nitrate and moisture content of soil throughout

Date	Depth	UNCROPPED AREA					
		Unmanured plot			Manured plot		
		% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
			Grm. per 100 grm.	lb. per acre		Grm. per 100 grm.	lb. per acre
5th October 1926.	0— 6	35·3	·0013	19·09	36·1	·0014	21·26
	6—12	33·1	·00092	13·81	33·2	·0010	15·75
	12—18	33·9	·00059	8·91	32·8	·00052	7·86
	18—24	36·5	·00054	8·13	32·6	·00046	6·84
	24—30	38·1	·00055	8·23	36·6	·00041	6·11
	30—36	40·1	·00056	8·38	38·1	·00069	10·29
				66·55			68·11
13th October 1926.	0— 6	32·2	·00091	13·66	32·1	·0012	18·51
	6—12	32·7	·00065	9·89	32·5	·00065	9·77
	12—18	35·0	·00040	6·00	33·5	·00059	8·89
	18—24	37·7	·00041	6·16	36·1	·00054	8·10
	24—30	38·2	·00041	6·18	36·9	·00054	8·15
	30—36	40·4	·00056	8·41	38·6	·00090	13·44
				50·30			66·86
20th October 1926.	0— 6	25·2	·00067	10·03	26·6	·00062	9·25
	6—12	27·3	·00050	7·47	30·5	·00038	5·77
	12—18	32·8	·00039	5·88	32·7	·00033	4·89
	18—24	35·5	·00033	5·02	34·7	·00040	6·00
	24—30	36·8	·00034	5·08	36·5	·00034	5·07
	30—36	38·0	·00041	6·17	36·7	·00041	6·10
				39·62			37·08
28th October 1926.	0— 6	21·9	·00059	8·82	22·8	·00053	8·02
	6—12	27·3	·00050	7·46	26·3	·00043	6·45
	12—18	31·5	·00019	2·91	32·5	·00039	5·86
	18—24	33·4	·00033	4·93	34·2	·00033	4·97
	24—30	37·8	·00041	6·16	35·5	·00033	5·03
	30—36	35·9	·00034	5·04	36·0	·00034	5·05
				35·32			35·38

PERIOD (*b*)—*contd.*

the period 16th April—28th October 1926—contd.

CROPPED AREA					
UNMANURED PLOT			MANURED PLOT		
% Water on dry soil	$NaNO_3$ in dry soil		% Water on dry soil	$NaNO_3$ in dry soil	
	Grm. per 100 grm.	lb. per acre		Grm. per 100 grm.	lb. per acre
31·2	·00054	8·10	36·0	·00074	11·12
32·8	·00052	7·84	31·3	·00064	9·66
31·8	·00039	5·83	33·2	·00052	7·88
31·9	·00039	5·84	35·3	·00054	8·04
36·0	·00034	5·05	36·6	·00047	7·11
37·7	·00041	6·16	36·5	·00041	6·08
		38·82			49·89
32·5	·00059	8·79	33·7	·00092	13·84
31·9	·00045	6·81	31·0	·00071	10·60
32·5	·00046	6·84	34·3	·00040	5·97
32·8	·00039	5·89	36·1	·00040	6·07
35·6	·00020	3·02	37·3	·00041	6·13
36·9	·00020	3·06	36·5	·00041	6·09
		34·41			48·70
24·9	·00036	5·46	27·5	.00031	4·67
28·4	·00038	5·64	29·6	·00038	5·71
30·7	·00038	5·78	33·0	·00033	4·91
31·2	·00052	7·73	34·6	·00020	3·00
32·0	·00045	6·83	35·3	·00033	5·02
35·1	·00040	6·01	34·9	·00033	5·01
		37·45			28·32
23·3	·00030	4·47	22·0	·00041	6·18
27·5	·00031	4·66	26·7	·00044	6·54
29·4	·00025	3·80	28·0	·00044	6·56
31·1	·00039	5·79	30·8	·00032	4·81
37·5	·00034	5·13	32·8	·00033	4·90
34·1	·00040	5·96	32·7	·00039	5·88
		29·81			34·87

The above figures are set out diagrammatically in Chart II.

The first interesting point in regard to the above table arises out of the first two sets of analyses carried out on 16th April 1926 and 30th April 1926 respectively. By comparison with the figures for the same plots in Table I, it will be seen that between 8th to 16th April 1926 a distinct loss of nitrate has taken place in these plots and on 30th April 1926 the loss is much greater, being particularly marked in the surface 6″. Since there was no drainage at this time and no crop on the land, the nitrate has either suffered denitrification or has undergone transformation into some other compound.

The slight falls of rain in early April amounting to about 1″ in all have caused a distinct increase in the nitrate content of the soil sampled on 13th May 1926. Yet at the date of sampling, the surface soil only contained from 9 to 10 per cent. moisture. This is too low a content to allow of nitrification and it would appear that nitrification must be a fairly rapid process and that the rain falling between 7th and 12th May was sufficient to raise the moisture say of the top 1 or 2″ of soil to the necessary content for nitrification and that this process set in almost immediately.

Before the next sample was taken on the 21st May nearly 5″ of rain fell. This amount of rain at such a date is abnormal at Nagpur. It is interesting to note that it only affected the moisture content of the top 18″ of soil. On the unmanured plot set apart for cropping, it appears to have affected the moisture content throughout the top three feet when the figures are compared with those of the sample taken on the 13th May. These latter figures appear to be low, however, and comparison with the sample taken on 16th and 30th April indicate that this 5″ of rainfall has not affected the soil below 18″ in depth.

The nitrate content of the soil showed a large increase as a result of this 5″ fall of rain. On the 21st and 22nd May there was a further fall of $\frac{3}{4}$″ of rain. The plots were again sampled on the 24th May and the top 18″ of soil had dried out considerably as a result of the $2\frac{1}{2}$ days intervening dry weather. The nitrates, however, still further increased in amount and Chart II indicates clearly that this extra nitrate formation has taken place in the top 6″ of soil. Moreover, it is obvious that more nitrification has taken place on the manured than on the unmanured plots. There was practically no more rain until the 1st July except for a few very light showers. The soil steadily dried out as evidenced by all the samples taken up to and including those of 9th June. The nitrate remained fairly constant from 24th May to 1st June except for a large gain in the surface 6″ of the manured plot destined for cropping. In the sample taken on the 4th June this plot again behaved abnormally losing about $\frac{1}{2}$ its nitrate in 3 days, whereas the nitrate content of the other plots remained fairly constant. The loss of nitrate in this one plot was undoubted, being far outside the experimental error and is difficult to account for. After this date there was in general a fairly steady gain in nitrate in all the plots right up to the end of June. Yet the

moisture content of the surface soil throughout this month was usually between 12 and 16 per cent. Black cotton soil with this content of moisture appears very dry and work in this laboratory in the past has indicated that no nitrification takes place in the soil when the moisture content is as low as this. But in the field nitrification obviously does take place under these conditions. In the samples taken on 16th June, there is a distinct increase in the nitrate content over those taken on the 9th June and it seems hardly possible that this increase could have been due to the ·05″ of rain received on the night of the 15-16th June—a few hours before the samples of the 16th were taken. The figures and Chart for June again show clearly that the nitrates are being formed mainly in the top 6″ of soil and that the manured plots are richer in nitrates than the unmanured plots.

The rains broke in full force early in July and approximately 12″ of rain fell between the 1st and 9th July on which latter date the next samples were taken. The Table shows that on this date the moisture content throughout the whole 3 feet depth was uniform in the case of each plot, running from 35-40 per cent. The nitrate was more or less evenly distributed throughout the 3 feet layer of soil, as is well seen in Chart II. There was, moreover, a still further increase in the total nitrate content of the soil. This increase probably took place between the date of the last sampling 30th June and the heavy rainfall recorded at 8 A.M. on the 4th July and possibly to some extent on the 6th and 7th July when there was a slight break in the rains. The drains began running on the 10th July and this flow was kept up in full force by a further fall of over 6″ of rain before the next samples were taken on the 14th July. A large amount of nitrate passed away in the drainage water and no doubt much more passed below the reach of the drains. In consequence, the nitrate content of three of the plots suffered a large loss; yet strangely enough the uncropped manured plot showed an actual gain of nitrate. Only a few light showers fell between the 14th and 19th July, on which latter date the next samples were taken. The drains ceased to flow on the 15th and did not run again until early in August. On the 19th July the moisture content of the top one foot of soil was 3 to 6 per cent. less than on the 14th July. Nitrification had obviously restarted as shown by the increase in the nitrate content of the top 6″ in each plot. There was distinctly less nitrate in the bottom foot of the uncropped unmanured plot than was present on the 14th July. Except for a very light shower of ·03″ on the 23rd, no rain fell between the 19th July and the date of the next sampling—24th July. Nitrification had gone on distinctly in the top 6″ in all cases as shown by the increase in nitrates in that layer and this was particularly marked in the two manured plots. The uncropped manured plot, however, showed a loss of total nitrate in the whole 3 feet since the previous sampling. Since there was no drainage at this time, it would appear that denitrification has taken place.

Nearly an inch of rain fell before the date of the next sampling on the 29th July and on this date there was a considerable increase of nitrate in all the plots since

the previous sampling. The 1″ of rain, however, had washed a good deal of the surface nitrate down into the second foot.

A further 6″ of rain fell before the next samples were taken on 9th August. The flow from the drains restarted on the 4th August.

It will be seen from Table II and from Chart No. II that much loss of nitrate had taken place from the soil. Rain fell more or less continuously throughout the month, the drains ran regularly and the nitrate content of all the plots showed a steady fall throughout August. From the 23rd to 26th of the month there was a slight break in the rains and in the samples taken on the 24th a very slight recovery of the nitrate content was indicated. Throughout the whole of August the moisture content in all the plots through the top 3 feet was almost always over 35 per cent. and frequently reached 40 per cent.

The drains were still running feebly when the next set of samples was taken on the 2nd September and a further slight diminution of the nitrate content of the soil was observed. The crop at this time was now becoming quite big and throughout September and the first half of October the nitrate content of the cropped plots was steadily less than that of the uncropped plots. The difference was small but we think significant and it is especially apparent if the top foot of soil only is considered. It is only natural as the roots of the cotton plant are probably mainly distributed in the top foot of soil. Drainage ceased after about the 4th September. There was a fall of 2″ of rain on the 10th of this month and a few light showers a few days later. The effect of this rain was distinct in increasing nitrification in the surface 6″ in the samples taken on the 16th and 22nd September. There was practically no more rain till the 3rd October and there was no flow from any of the drains. Yet when the next sample was taken on the 28th September all 4 plots had suffered a heavy loss of nitrate. In the case of the cropped plots one might have expected this, but in the case of the uncropped ones it is difficult to account for this loss unless we assume that denitrification was taking place. There was a fall of $1\frac{1}{4}$″ of rain on the 3rd October and this caused a small amount of nitrification as shown by the analyses made on the 5th of that month.

No rain fell after the 9th October and when samples were taken on the 20th October, only very small amounts of nitrate were left in any of the plots. By this time, the water content of the soil had considerably diminished, the surface soil in particular having lost a large amount of water.

Conclusions.

The comparison between the figures for 1925 and 1926 is not complete, since in 1925 the first samples were not taken until 21st June, whereas the 1926 series began in April. The maximum nitrate content of the plots was reached very quickly in 1925, *viz.*, on the 25th June. This was probably due to the frequent light showers in May and to the almost regular showers with no excessive falls in the first 3 weeks of June. The increase in nitrate in 1926 was much less sudden and all throughout 1926 the plots contained distinctly less nitrate than in 1925. This is probably

due to the fact that July 1926 was much wetter than July 1925, 21″ and 15·5″ of rain respectively falling in these 2 months. The rainfall in July 1926 was also more or less continuous and the continual drainage through the soil did not allow of the accumulation of nitrates even if they were actually formed.

2. The loss of nitrate on each of the four plots can be computed in the same way as was done on page 173 for period (*a*).

The losses are as follows in lb. nitrate of soda per acre.

Unmanured uncropped plot—229.
Manured uncropped plot—348.
Unmanured cropped plot—268.
Manured cropped plot—374.

These figures are distinctly less than the losses in the previous year. These figures are, of course, much lower than the actual losses which take place since we have only taken note of large losses and also our analyses were not done at sufficiently short intervals to follow all the changes in nitrate content which take place.

From a consideration of the foregoing results, it would appear to be indicated that nitrification takes place only in the rains and that at the end of the rains when the soil dries out, the process ceases. In our experiments it would appear that the heavy rains washed out the nitrate and from other causes also the nitrate diminished, so that during the cold weather only very small amounts of nitrate were present in the soil. In our experiments, however, the crop was not removed till mid November and hence the land received no cultivation after the cessation of the rains. Under normal conditions, however, if a cold weather crop is to be sown, the land is harrowed and ploughed after the rains in preparation for that crop. It appeared necessary to see whether under these conditions any nitrate was present in the soil in the cold weather. The effect of this is seen in period (*c*).

Period (*c*). November 1st 1926 to date (January 1927).

As explained on page 158 the following plots were included in the experiments from November 1st onwards.

1. Uncropped unmanured uncultivated.
2. Uncropped manured uncultivated.
3. Cropped unmanured uncultivated.
4. Cropped manured uncultivated.
5. Uncropped unmanured cultivated.
6. Uncropped manured cultivated.
7. Plot III, uncropped unmanured cultivated.

Plots 1, 2, 3 and 4 were the same plots as had been sampled in period (*b*) and plots 5 and 6 were portions of plots (1) and (2) respectively. As above stated, the cultivation on these was very deficient as it was taken in hand too late.

The results are set out in Table III and in the Chart II. It will be seen from the Table that all the above 6 plots were not sampled at each sampling. Thus on

TABLE

Period

Date	Depth	UNCROPPED AREA								
		UNCULTIVATED						CULTIVATED		
		UNMANURED			MANURED			UNMANURED		
		% water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: Lb. per acre	% water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: Lb. per acre	% water on dry soil	$NaNO_3$ in dry soil: Grm. per 100 grm.	$NaNO_3$ in dry soil: Lb. per acre
1	2	3	4	5	6	7	8	9	10	11
1st November 1926.	0—6	20·9	·00087	13·0	23·3	·00054	8·0	19·1	·00069	10·3
	6—12	27·2	·00043	6·5	26·9	·00025	3·7	24·0	·00052	7·8
	12—18	30·5	·00032	4·8	30·0	·00013	1·9	28·4	·00038	5·6
	18—24	34·2	·00033	5·0	35·7	·00034	5·0	29·4	·00032	4·7
	24—30	39·9	·00034	5·2	36·1	·00034	5·0	30·3	·00032	4·8
	30—36	38·5	·00034	5·2	33·5	·00033	4·9	27·5	·00031	4·7
				39·7			28·5			37·9
13th November 1926.	0—6	16·5	·00055	8·3	16·7	·00067	10·0	..	..	..
	6—12	24·4	·00048	7·2	22·0	·00047	7·1	..	..	..
	12—18	31·7	·00052	7·8	27·0	·00049	7·4	..	..	..
	18—24	33·9	·00033	4·9	31·0	·00045	6·7	..	..	..
	24—30	33·4	·00039	5·9	36·4	·00041	6·1	..	..	..
	30—36	40·2	·00042	6·3	34·7	·00040	6·0	..	..	..
				40·4			43·3			
15th November 1926.	0—6	23·9	·00042	6·3	21·0	·00058	8·7	16·2	·0011	16·5
	6—12	28·5	·00031	4·7	26·1	·00043	6·4	24·6	·00048	7·3
	12—18	33·9	·00040	5·9	30·5	·00032	4·8	26·6	·00037	5·5
	18—24	33·9	·00033	4·9	30·0	·00032	4·8	28·0	·00037	5·6
	24—30	37·5	·00041	6·2	30·7	·00032	4·8	26·3	·00037	5·5
	30—36	36·8	·00034	5·1	34·4	·00033	5·0	28·0	·00037	5·6
				33·1			34·5			46·0
24th November 1926.	0—6	21·1	·00041	6·1	20·1	·00052	7·8	16·2	·0010	15·0
	6—12	27·1	·00037	5·6	27·6	·00044	6·5	25·4	·00049	7·3
	12—18	28·9	·00038	5·7	29·0	·00038	5·7	23·8	·00042	6·3
	18—24	33·0	·00039	5·9	32·4	·00033	4·9	28·2	·00038	5·6
	24—30	34·2	·00053	8·0	35·1	·00033	5·0	34·0	·00040	6·0
	30—36	34·3	·00040	6·0	32·6	·00033	4·9	33·1	·00039	5·9
				37·3			34·8			46·1

III

(c)

CROPPED AREA											
CULTIVATED			UNCULTIVATED AFTER REMOVAL OF CROP						UNCROPPED, CULTIVATED		
MANURED			UNMANURED			MANURED			UNMANURED		
% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil	
	Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
12	13	14	15	16	17	18	19	20	21	22	23
21·6	·00053	7·9	..	..	..	..	..	..	28·2	·0040	60·1
24·8	·00049	7·3	..	..	..	..	..	..	29·9	·0023	34·4
28·8	·00038	5·7	..	..	..	..	..	..	34·3	·0012	17·9
30·3	·00032	4·8	..	..	..	..	..	..	36·3	·00094	14·2
34·4	·00040	6·0	..	..	..	..	..	..	38·5	·00083	12·4
34·8	·00040	6·0	..	..	..	..	..	..	39·2	·00083	12·5
		37·7									151·5
..	..	..	18·9	·00034	5·1	17·6	·00039	5·9	..	..	..
..	..	..	25·6	·00030	4·6	24·0	·00036	5·4	..	..	..
..	..	..	30·0	·00032	4·8	26·0	·00043	6·4	..	..	..
..	..	..	30·9	·00038	5·8	28·4	·00031	4·7	..	..	..
..	..	..	31·5	·00039	5·8	32·0	·00032	4·9	..	..	..
..	..	..	31·4	·00032	4·8	31·4	·00032	4·8	..	..	..
					30·9			32·1			
16·6	·00072	10·8	..	..	..	..	..	..	19·4	·0046	69·0
25·0	·00049	7·3	..	..	..	..	..	..	28·2	·0025	37·6
26·5	·00037	5·5	..	..	..	..	..	..	32·7	·0014	21·6
29·9	·00038	5·7	..	..	..	..	..	..	31·6	·0012	18·4
29·6	·00038	5·7	..	..	..	..	..	..	35·1	·00094	14·0
30·1	·00045	6·7	..	..	..	..	..	..	37·7	·00082	12·3
		41·7									172·9
16·8	·00055	8·3	..	..	..	..	..	..	29·3	·0038	57·0
22·2	·00041	6·2	..	..	..	..	..	..	29·6	·0016	24·8
28·4	·00044	6·6	..	..	..	..	..	..	29·7	·0020	29·6
27·2	·00043	6·5	..	..	..	..	..	..	30·1	·0015	23·0
31·0	·00045	6·7	..	..	..	..	..	..	34·0	·00079	11·9
28·5	·00044	6·6	..	..	..	..	..	..	35·0	·00080	12·0
		40·9									158·3

TABLE

Period

Date	Depth	UNCROPPED AREA								
		UNCULTIVATED						CULTIVATED		
		UNMANURED			MANURED			UNMANURED		
		% water on dry soil	NaNO₃ in dry soil		% water on dry soil	NaNO₃ in dry soil		% water on dry soil	NaNO₃ in dry soil	
			Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
1	2	3	4	5	6	7	8	9	10	11
29th November 1926.	0—6	20·5	·00063	9·5	19·4	·00086	12·9	..	..	..
	6—12	28·4	·00044	6·6	25·9	·00049	7·3	..	..	..
	12—18	30·8	·00038	5·8	29·1	·00044	6·6	..	..	..
	18—24	27·7	·00037	5·6	32·8	·00052	7·8	..	..	..
	24—30	35·7	·00047	7·1	34·6	·00046	7·0	..	..	..
	30—36	34·7	·00040	6·0	34·4	·00033	5·0	..	..	..
				40·6			46·6			
2nd December 1926.	0—6	17·7	·00056	8·5	20·3	·00040	6·0	13·0	·00075	11·2
	6—12	27·9	·00056	8·4	25·3	·00043	6·4	25·1	·00049	7·3
	12—18	31·5	·00058	8·7	26·7	·00037	5·6	26·8	·00043	6·5
	18—24	28·3	·00056	8·5	27·8	·00050	7·5	28·3	·00044	6·6
	24—30	31·1	·00058	8·7	34·1	·00046	6·9	34·7	·00040	6·0
	30—36	30·0	·00051	7·7	31·4	·00045	6·8	35·3	·00054	8·0
				50·5			39·2			45·6
7th December 1926.	0—6	17·6	·00067	10·0	15·5	·00066	9·9	11·7	·00074	10·1
	6—12	24·9	·00049	7·3	23·9	·00048	7·2	23·1	·00042	6·2
	12—18	26·0	·00049	7·4	25·2	·00049	7·3	28·4	·00038	5·6
	18—24	31·8	·00045	6·8	28·5	·00050	7·5	30·0	·00045	6·7
	24—30	35·5	·00040	6·0	33·3	·00053	7·9	36·3	·00047	7·1
	30—36	33·3	·00039	5·9	33·1	·00046	6·9	34·6	·00040	6·0
				43·4			46·7			41·7
17th December 1926.	0—6	18·7	·00091	13·7	20·0	·0018	27·6	19·5	·00057	8·6
	6—12	24·8	·00042	6·3	21·8	·00047	7·0	24·7	·00042	6·4
	12—18	29·9	·00038	5·7	28·0	·00037	5·6	30·0	·00045	6·7
	18—24	32·4	·00039	5·9	27·3	·00031	4·7	31·3	·00045	6·8
	24—30	35·0	·00040	6·0	31·4	·00039	5·8	35·0	·00040	6·0
	30—36	34·3	·00039	6·0	32·2	·00039	5·8	36·3	·00040	6·1
				43·6			56·5			40·6

III—*contd.*

(*c*)—contd.

CROPPED AREA											
CULTIVATED			UNCULTIVATED AFTER REMOVAL OF CROP						UNCROPPED, CULTIVATED		
MANURED			UNMANURED			MANURED			UNMANURED		
% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil	
	Grm. per 100 Grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm per. 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
12	13	14	15	16	17	18	19	20	21	22	23
..	..	..	19·8	·00029	4·3	22·2	·00041	6·2	..	..	..
..	..	..	23·5	·00030	4·5	25·8	·00037	5·5	..	..	..
..	..	..	26·1	·00037	5·5	25·3	·00043	6·4	..	..	..
..	..	..	24·7	·00030	4·5	28·3	·00044	6·6	..	..	..
..	..	..	29·7	·00032	4·8	34·3	·00040	6·0	..	..	..
..	..	..	31·3	·00032	4·8	33·7	·00033	4·9	..	..	..
					28·4			35·6			
16·8	·00100	15·0	..	..	..	..	..	..	23·9	·0036	54·0
25·1	·00061	9·1	..	..	..	..	..	..	26·8	·0012	17·6
26·9	·00043	6·5	..	..	..	..	..	..	28·2	·0012	17·8
27·6	·00044	6·5	..	..	..	..	..	..	30·0	·0011	17·2
30·0	·00045	6·7	..	..	..	..	..	..	33·9	·00092	13·9
33·5	·00039	5·9	..	..	..	..	..	..	33·9	·00092	13·9
		49·7									134·4
13·6	·00091	13·7	..	..	..	..	..	..	22·9	·0038	57·5
24·6	·00093	10·9	..	..	..	..	..	..	28·5	·0017	26·4
26·6	·00062	9·2	..	..	..	..	..	..	30·2	·00096	14·4
27·3	·00062	9·3	..	..	..	..	..	..	32·7	·00065	9·8
33·8	·00053	7·9	..	..	..	..	..	..	34·6	·00086	13·0
32·7	·00046	6·8	..	..	..	..	..	..	35·2	·00074	11·0
		57·8									132·1
18·2	·00073	11·0	..	..	..	..	..	..	24·7	·0046	69·0
22·3	·00041	6·2	..	..	..	..	..	..	25·7	·0027	40·3
26·8	·00043	6·5	..	..	..	..	..	..	30·0	·0012	18·2
28·1	·00037	5·6	..	..	..	..	..	..	29·6	·0013	19·0
30·7	·00045	6·7	..	..	..	..	..	..	34·6	·00093	14·0
29·6	·00032	4·8	..	..	..	..	..	..	32·8	·00105	15·7
		40·8									176·2

TABLE

Period

Date	Depth	UNCROPPED AREA								
		UNCULTIVATED						CULTIVATED		
		UNMANURED			MANURED			UNMANURED		
		% water on dry soil	NaNO$_3$ in dry soil: Grm. per 100 grm.	NaNO$_3$ in dry soil: Lb. per acre	% water on dry soil	NaNO$_3$ in dry soil: Grm. per 100 grm.	NaNO$_3$ in dry soil: Lb. per acre	% water on dry soil	NaNO$_3$ in dry soil: Grm. per 100 grm.	NaNO$_3$ in dry soil: Lb. per acre
1	2	3	4	5	6	7	8	9	10	11
22nd December 1926.	0—6	16·0	·0010	15·0	14·4	·00103	15·4	13·9	·00097	14·6
	6—12	27·1	·00059	8·8	22·2	·000472	7·1	25·3	·00058	8·7
	12—18	26·5	·00058	8·8	25·4	·000426	6·4	27·8	·00062	9·4
	18—24	34·7	·00060	9·0	28·6	·000378	5·7	30·7	·00051	7·7
	24—30	36·2	·00061	9·1	30·3	·000512	7·7	30·8	·00064	9·6
	30—36	33·1	·00059	8·8	33·3	·000458	6·9	31·4	·00064	9·7
				59·5			49·2			59·7
4th January 1927.	0—6	15·2	·00066	9·9	13·0	·000588	8·8	..	..	..
	6—12	25·0	·00036	5·4	26·2	·000369	5·5	..	..	..
	12—18	30·5	·00051	7·7	25·4	·000366	5·5	..	..	..
	18—24	30·8	·00032	4·8	30·3	·000384	5·8	..	..	..
	24—30	27·7	·00044	6·6	33·0	·000458	6·9	..	..	..
	30—36	28·0	·00025	3·7	36·6	·000405	6·1	..	..	..
				38·1			38·6			
6th January 1927.	0—6	10·0	·00114	17·2	10·0	·00104	15·6	10·8	·00110	16·5
	6—12	23·2	·00060	8·9	23·1	·000476	7·1	24·5	·00054	8·2
	12—18	26·2	·00043	6·4	24·4	·000542	8·1	24·6	·00048	7·3
	18—24	23·5	·00031	5·4	22·4	·00059	8·9	24·6	·00542	8·1
	24—30	25·2	·00048	7·3	24·0	·00048	7·2	27·5	·00056	8·4
	30—36	22·3	·00047	7·1	24·1	·00054	8·1	27·5	·00062	9·3
				52·3			55·0			57·8
				Tractor	*ploughed.*					
12th January 1927.	..	..	..	..	..	..	..	13·8	·00097	14·6
	..	..	..	..	..	..	..	23·3	·00053	8·0
	..	..	..	..	..	..	..	28·4	·00059	8·9
	..	..	..	..	..	..	..	30·4	·00044	6·7
	..	..	..	..	..	..	..	33·5	·00062	9·4
	..	..	..	..	..	..	..	31·8	·00052	7·8
										55·34

III—*contd.*

(*c*)—contd.

CROPPED AREA											
CULTIVATED			UNCULTIVATED AFTER REMOVAL OF CROP						UNCROPPED, CULTIVATED		
MANURED			UNMANURED			MANURED			UNMANURED		
% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil		% water on dry soil	$NaNO_3$ in dry soil	
	Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre		Grm. per 100 grm.	Lb. per acre
12	13	14	15	16	17	18	19	20	21	22	23
12·4	·00106	15·9	..	..	..	..	..	..	16·5	·00488	73·3
24·2	·00060	9·0	..	..	..	..	..	..	24·6	·00223	33·8
26·4	·00055	8·3	..	..	..	..	..	..	31·0	·00129	19·5
30·4	·00051	7·7	..	..	..	..	..	..	31·5	·00090	13·6
31·4	·00058	8·7	..	..	..	..	..	..	31·4	·00116	17·4
29·3	·00057	8·6	..	..	..	..	..	..	33·1	·00118	17·7
		58·2									175·1
..	..	..	12·3	·00048	7·2	16·3	·00039	5·8	..	..	..
..	..	..	23·6	·00030	4·5	26·0	·00037	5·5	..	..	..
..	..	..	22·9	·00042	6·2	26·5	·00030	4·6	..	..	..
..	..	..	27·5	·00031	4·7	22·4	·00032	4·9	..	..	..
..	..	..	26·8	·00043	6·5	34·1	·00040	5·9	..	..	..
..	..	..	30·6	·00026	3·8	33·6	·00040	5·9	..	..	..
					32·9			32·6			
11·0	·00073	11·0	..	..	..	..	..	..	15·7	·00574	86·1
21·3	·00053	7·9	..	..	..	..	..	..	25·4	·00134	20·1
23·3	·00053	8·0	..	..	..	..	..	..	26·0	·00111	16·6
24·4	·00054	8·1	..	..	..	..	..	..	26·9	·00087	13·0
27·0	·00056	8·4	..	..	..	..	..	..	30·9	·00090	13·5
26·8	·00050	7·4	..	..	..	..	..	..	31·4	·00090	13·5
		50·8									162·8
					Tractor	*ploughed.*					
12·9	·00059	8·8	15·5	·00055	8·2	12·7	·00064	9·6	17·7	·00542	81·4
21·0	·00055	8·3	25·0	·00036	5·5	20·2	·00057	8·6	25·0	·0017	25·5
28·4	·00063	9·4	25·6	·00024	3·7	27·2	·00037	5·6	30·0	·00095	14·4
27·3	·00059	8·8	27·3	·00031	4·7	30·3	·00045	6·7	31·0	·00077	11·6
31·4	·00061	9·2	29·8	·00055	8·3	31·1	·00052	7·7	35·0	·00073	11·0
32·8	·00059	8·8	30·4	·00051	7·7	28·5	·00044	6·6	33·6	·00105	15·8
		53·3			38·1			44·8			159·7

13th November 1926 and 29th November 1926 the experiments were merely a continuation of the experiments in series (*a*) and no cultivated area was sampled on these two dates.

Throughout the period under experiment there was no rain except for a fall of 0·69″ on December 17th.

As regards the effect of cultivation on the original plots, it will be seen from the Table and Chart that the effect was practically negligible. All these plots contained very small amount of nitrates. There is some slight indication that cultivation had increased the nitrate in the surface soil, but it is doubtful if the difference observed lies outside the experimental error. As regards plot No. 7, referred to as plot No. III, uncropped unmanured cultivated, it will be seen that it contains large amounts of nitrates particularly in the surface 6″. It is unfortunate that analyses of this plot were only commenced on November 2nd. However, the soil of this field is apparently identical in every respect with the soil in the other plots under experiment. The only difference was in the cultivations carried out. It will be as well to compare the cultivation on this plot with that on the other 2 cultivated plots under observation in Series (*c*).

Cultivations on plots (3) and (4) *viz.* uncropped unmanured cultivated plots and uncropped manured cultivated plots.

August, September—*Nil.*
29th October—Ploughing.
31st October—Bakharing.
5th November—Clods broken by hand.
12th November—Clods broken by clod crusher.

Cultivations on plot No. 7 (Plot III) uncropped *unmanured* cultivated.

12th September—Tractor bakharing followed by spring tooth cultivator.
24th September—Tractor bakharing followed by spring tooth cultivator.
19th October—Bakharing.
22nd October—Harrowing.

There can be no doubt that the increased nitrate content of plot No. 7 is due to the more efficient cultivations it received as compared with plots (3) and (4).

Conclusion.

At the end of the rains, the black cotton soil of Nagpur contains only small amounts of nitrates. If the soil remains uncultivated throughout the cold weather no nitrate formation takes place. If, however, the soil is kept well cultivated at the end of the rains, large amounts of nitrates are formed in the surface soil and are available for the cold weather crops. By way of confirmation of this conclusion, we have available the results of analyses carried out in other plots which received efficient cultivations at the end of the rains.

Date	Depth	Lb. $NaNO_3$ per acre dry soil		
		Near alkaline well	Students' well	Limed plot
1st November 1926	0—6	47·9	44·8	
	6—12	22·4	15·1	
	12—18	11·5	13·5	
	18—24	11·8	9·8	
	24—30	9·9	15·9	
	30—36	11·6	13·9	
		115·1	113·0	
15th November 1926	0—6	..	..	71·8
	6—12	..	..	35·9
	12—18	..	..	17·4
	18—24	..	..	13·8
	24—30	..	..	12·2
	30—36	..	..	10·1
				161·2
10th January 1927	0—6	77·8	71·9	
	6—12	43·0	40·4	
	12—18	20·8	28·9	
	18—24	24·6	22·2	
	24—30	21·3	27·8	
	30—36	23·2	18·4	
		210·7	209·6	

It will be seen that the amounts of nitrate present in these soils is very high and its formation must be due to the cultivations received at the end of the rains and in the early cold weather.

Summary and recommendations.

I. The amount of nitrate produced in the soil and its bearing on the growth of crops in the Central Provinces.

In the work described above, data have been given for the amount of nitrate present in black cotton soil at Nagpur throughout the year. Plots both with and without crops were under experiment and the effect of cultivation after the rains on the nitrate content of the soil was also examined.

In the first place, it will be of interest to compare the amounts of nitrates found by us with those found by other workers in India, Egypt and England.

Our own results show that in April when the nitrate content of our soil is lowest, the soil throughout the top 3 feet examined contains on an average about 1 part of nitrate nitrogen per million of dry soil, or say 9 lb. of nitrate of soda per acre

in the top 6″ of soil. When nitrification has become well established after the break of the rains, the surface 6″ of soil frequently contains 5 or 6 parts per million and the second 6″ rather less. The maximum figure found by us was on June 21st, 1926, on a manured plot, the top 6″ of which contained nitrate nitrogen equal to 10 parts per million of dry soil and the second 6″ contained nitrate nitrogen equal to 3½ parts per million.

At Pusa on the Gangetic alluvium, Leather obtained somewhat similar results to ours. He found that towards the end of the hot weather the surface soil contained about 1 part per million of nitrate nitrogen. After the first fall of rain this showed a rapid increase to 2½ parts per million in the surface 6″ and to 12 parts per million in the second six inches.

At Cawnpore also in the Gangetic alluvium, Clarke and co-workers found 2·4 parts of nitrate nitrogen per million parts of dry soil in the top foot at the end of the rains, on September 14th. As a result of cultivation, this figure rose to 14·4 parts per million by the following March. Clarke did not continue his experiments during the rains.

Turning to work carried out by Prescott[1] in Egypt, we get figures of a very different order. Apparently in the hot dry weather the summer fallow land is very dry and then contains only 2·7 parts of nitrate nitrogen per million of dry soil. Yet this figure is far higher than we found in Indian soils in the dry hot weather. When we turn to the irrigated cotton soils of Egypt, however, we find that the amount of nitrate nitrogen is far higher than anything we ever experience in India. It rarely falls as low as 20 parts per million of dry soil and is usually between 30 and 40 parts and at times reaches 60 parts per million.

It may be of interest to mention figures obtained by Russell[2] at Rothamsted. The unmanured plot in the Broadbalk field was found to contain nitrate nitrogen varying in amount from 1 to 6 parts per million throughout the year. The figures for the dunged plot varied from 4 to 16 parts and for the double ammonia salts plot from 3 to 31 parts per million of dry soil.

It thus appears that, under conditions prevailing on the black cotton soils of Central India, the amount of nitrification taking place during the growing period of the cotton crop is far smaller than that which takes place in Egypt during the cotton growing season. Under Egyptian conditions, the crop is grown in the hot weather under irrigation and thus both moisture and temperature conditions are favourable for nitrification. In Central India the crop is grown in the rainy season. When the first rains fall, rapid nitrification takes place, but the amount of nitrate produced never approaches the amounts of nitrate produced in Egyptian soils. Moreover, the crop is too small to take advantage of the nitrate produced at this early stage. Subsequent heavy falls of rain wash the nitrate out of the soil and if, as frequently happens in India, rain falls more or less continuously for weeks on end the cotton

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[1] *Jour. Agri. Sci.*, Vol. IX, 1919, p. 216.
[2] *Jour. Agri. Sci.*, Vol. VI, 1914, p. 28.

crop suffers from nitrogen starvation. In Egypt the regular irrigations keep up a large store of nitrates in the soil and Prescott[1] states that "The cotton crop in Egypt at the present time is indeed independent of the artificial application of fertilisers." It is not surprising that the cotton outturns in Central India compare so unfavourably with those of Egypt. This matter could be remedied to some extent by the judicious use of nitrogenous fertilisers. At the same time great skill is necessary in order that these should be applied at the right time. One wants to put them on after a heavy fall of rain, but if further heavy rain falls subsequent to the application of the fertiliser it is simply washed down into the soil out of reach of the crop.

One is almost inevitably drawn to the conclusion that cotton is hardly the crop to grow in the Berars. Certainly, its area is far too large. During recent years the high prices obtained have encouraged the growing of a large area of this crop. The indications are that the prices realisable in future will be on the pre war scale, yet the costs of production are hardly likely to go back to that level. Our results indicate that soil conditions are such that we can never hope to compete on a yield basis with Egypt and other centres where irrigation facilities are available. Therefore, it would seem that there should be an extension of the growth of *juari* and fodder and that some of the area now growing cotton would be better so employed. The improvement in the supply of fodder would improve the cattle by better feeding and with the provision of better cattle, agricultural operations would become more efficient, better crops could be obtained and the milk supply of the country could also be improved.

Groundnut in certain areas should prove an excellent substitute for cotton. Our results also indicate that efficient cultivation at the close of the rains encourages the production of quite a large store of nitrates in the soil and hence the possibility of extending the area of cold weather crops is worth investigation. Mr. Allan has dealt with the question of substitutes for cotton and with the extension of the *rabi* area in a note at the end of the Memoir.

II. The loss of nitrate from the soil.

The foregoing work has provided some indications of the enormous loss of nitrate which takes place from the black cotton soil of Central India during the rains.

Thus during the rains of 1925 a loss of nitrate nitrogen equivalent to 480 and 626 lb. of nitrate of soda per acre respectively was observed on an unmanured and manured plot cropped with cotton.

In the succeeding season the same plots cropped with *juar* lost respectively nitrate nitrogen equivalent to 268 and 374 lb. of nitrate of soda per acre. Similar uncropped plots lost nitrate nitrogen equivalent to 229 and 374 lb. of nitrate of soda per acre respectively. It must be remembered that these manured plots received during these periods of loss a top dressing of nitrate of soda equal to 65 lb. per acre.

[1] *Loc. cit.*, p. 218.

The method by which these losses have been estimated is essentially rough, but the results are undoubtedly on the low side. When we come to consider the results of our well water studies in Part III of this paper, it will be seen that the actual losses of nitrate nitrogen from our soil during the rains must be much greater than these figures indicate.

Table IV.

Experimental error in nitrate estimation.

As stated on page 159 each determination of nitrate in the soil was carried out on a composite sample made up by mixing four individual cores. Occasionally, however, these cores were analysed separately for moisture and nitrate content and certain of these determinations are set out below.

Depth	No. of core	Uncropped area				Cropped area			
		Unmanured		Manured		Unmanured		Manured	
		Sampled on 4-9-26		Sampled on 26-8-26		Sampled on 13-9-26		Sampled on 16-8-26	
		% Water on dry soil	Lb. $NaNO_3$ per acre on dry soil	% Water on dry soil	Lb. $NaNO_3$ per acre on dry soil	% Water on dry soil	Lb. $NaNO_3$ per acre on dry soil	% Water on dry soil	Lb. $NaNO_3$ per acre on dry soil
0—6″	1	34·3	11·9	33·9	14·9	35·3	8·0	44·6	18·5
	2	39·1	14·3	37·0	14·3	32·9	5·9	40·0	20·9
	3	36·6	14·2	34·9	12·0	31·1	5·8	41·5	19·1
	4	36·3	14·2	35·0	15·0	34·2	6·0	40·9	19·0
6—12″	1	34·3	11·9	34·6	13·9	34·1	7·9	39·3	15·6
	2	34·9	12·0	33·1	13·7	31·8	5·8	33·0	24·7
	3	33·8	11·9	34·3	11·9	31·0	5·8	38·9	15·5
	4	33·6	13·8	32·8	13·7	33·0	5·9	37·2	17·4
12—18″	1	37·0	10·2	37·9	10·3	34·6	5·8	35·5	11·1
	2	35·3	12·1	33·4	11·8	31·0	4·9	38·2	14·4
	3	37·0	12·2	36·5	10·2	32·6	4·0	38·4	13·4
	4	39·1	12·5	35·3	10·0	33·8	6·1	37·1	15·2
18—24″	1	39·3	11·4	39·1	10·4	36·7	5·9	36·8	11·2
	2	40·5	11·6	36·5	12·2	33·2	4·9	39·2	12·5
	3	38·7	11·4	41·8	10·6	33·0	4·5	38·4	14·5
	4	40·0	12·6	38·7	10·4	35·1	6·3	38·8	15·5
2 ″	1	36·3	22·3	40·3	21·0	39·9	4·0	37·0	24·5
	2	39·8	18·8	38·7	20·7	34·9	5·0	36·2	14·2
	3	41·1	16·9	39·7	16·7	35·3	4·1	36·7	13·2
	4	40·5	16·9	42·6	19·3	36·9	5·2	37·6	19·5
30— ″	1	38·6	25·2	38·6	20·7	38·8	3·0	36·4	17·2
	2	41·1	23·3	37·8	18·5	34·7	7·2	40·0	14·7
	3	43·6	19·4	39·0	16·6	38·4	4·0	39·9	14·6
	4	41·6	19·1	39·2	25·0	35·8		35·3	24·1

Table V.

Rainfall, 1925.

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	..	..	..	..	..	..	0·12	..	0·44	..	..	..
2	..	..	..	..	..	..	..	0·14	0·63	..	..	..
3	..	..	..	..	0·04	..	..	..	0·27	..	..	..
4	..	..	..	..	..	..	..	..	..	..	..	..
5	..	..	..	..	..	..	..	0·24	..	..	..	..
6	..	..	..	..	..	..	0·41	0·26	..	..	..	..
7	..	..	..	..	..	0·05	1·31	0·64	..	..	..	..
8	..		..	..	..	..	0·43	0·11	0·20	..	..	..
9	..	..	..	..	0·17	..	0·80	..	..	..	..	..
10	..	..	..	..	0·38	..	2·57	5·63	..	..	1·60	..
11	..	..	..	..	..	..	0·39	0·33	..	..	0·15	..
12	..	..	..	..	..	0·30	0·14	0·28	..	..	0·45	..
13	..	..	0·23	..	..	0·78	1·38	..	..	..	0·12	..
14	..	..	..	..	..	..	0·02	..	..	..	..	..
15	..	..	..	..	..	..	0·14	..	0·25	1·58	..	..
16	..	..	..	..	..	..	..	5·43	0·16	..	..	..
17	..	..	..	..	..	0·62	0·33	1·20	..	..	..	..
18	..	..	..	..	..	..	0·79	2·27	..	..	..	..
19	..	..	..	..	0·12	0·64	0·10	0·73	..	..	..	..
20	..	..	..	..	..	0·59	0·04	..	..	0·15	..	..
21	..	..	..	..	..	1·29	0·26	0·38	1·06	..	0·64	..
22	..	..	..	..	..	0·26	0·03	..	..	..	0·32	..
23	..	..	..	..	..	1·90	0·52	1·82	..	..	..	..
24	..	..	..	..	..	0·03	0·25	0·55	..	..	..	..
25	..	..	..	..	..	..	..	0·32	..	..	..	..
26	..	..	..	..	..	0·45	0·07	0·28	..	..	..	..
27	..	..	..	..	0·04	0·44	0·21	0·38	0·63	..	..	..
28	..	..	..	..	..	..	0·14	..	..	0·55	..	..
29	..	..	..	..	0·11	0·48	0·90	..	0·12	..	..	..
30	..	..	..	..	..	1·48	4·05	0·70	..	..	..	0·08
31	..	..	..	..	0·69	..	0·10	1·74	..	..	..	..
Total	..	..	0·23	..	1·55	9·31	15·50	23·43	3·76	2·28	3·28	0·08
Total for year	..	..	0·23	..	1·78	10·09	25·59	49·02	52·78	55·06	58·34	58·42

TABLE V.

Rainfall, 1926.

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
1	..	..	..	0·03	0·17	..	0·25	0·07	0·09	..	..
				0·02							
2	0·04	..	..	..	..	..	0·09	0·01	0·05	..	..
3	0·67	..	..	..	..	..	0·28	0·27	0·19	1·21	..
4	0·46	..	..	..	..	0·06	1·60	1·64	0·04	0·05	..
5	0·02	..	..	..	..	..	4·85	1·12	0·57	0·02	..
6	..	..	..	0·22	..	..	0·67	0·05	..	0·28	..
7	..	..	0·19	0·22	0·18	..	..	0·59	0·13	0·03	..
8	0·04	..	0·50	0·02	0·21	..	4·41	1·69	..	0·13	..
9	0·50	..	..	0·05	..	..	0·33	0·85	..	0·33	..
10	..	..	..	..	0·26	..	0·41	0·47	1·97	..	..
11	..	..	..	..	0·12	..	1·60	0·89	0·02	..	..
12	..	..	..	..	0·11	..	3·11	0·29	..	..	..
13	..	..	..	..	..	..	1·47	0·07	0·03	..	..
14	..	..	..	..	..	..	0·26	0·07	0·16	..	..
15	..	..	0·41	..	..	..	0·23	0·02	0·03	..	..
16	..	..	..	..	..	0·03	0·38	0·91	..	..	..
17	..	..	..	..	..	..	..	0·94	..	..	..
18	..	..	..	..	2·18	..	0·05	2·13	..	..	..
19	..	..	..	..	1·06	..	..	0·73	0·23	..	..
20	..	..	..	..	1·44	0·07	..	0·21	0·11	..	..
21	..	..	..	..	..	0·15	..	0·64	..	..	..
22	..	..	..	..	0·75	0·11	..	0·59	..	..	..
23	..	..	0·02	..	..	0·02	..	0·01	..	..	..
24	..	..	0·37	..	..	..	0·05	0·03	..	..	..
25	..	..	..	..	..	..	0·06	..	..	..	..
26	..	..	..	..	..	..	..	..	..	..	..
27	..	..	..	..	..	..	0·49	2·10	0·01	..	..
28	..	..	..	..	..	0·14	0·27	0·21	..	..	..
29	..	..	..	..	..	..	..	0·01	..	..	..
30	0·36	..	..	..	..	..	..	0·29	..	..	..
31	..	..	0·17	..	..	..	..	0·11	..	..	..
Total .	2·09	..	1·66	0·56	6·48	0·58	20·86	17·07	3·63	2·05	..
Total for year .	2·09	..	3·75	4·31	10·79	11·37	32·23	49·30	52·93	54·98	54·98

PART II.

SEASONAL COMPOSITION OF WELL WATERS AS A MEANS OF STUDY OF THE NITROGEN CYCLE IN THE SOIL.

In Part I of this paper attention has been drawn to the large amounts of nitrates formed in the soil during the early part of the rainy season at Nagpur. It was also shown that most of this nitrate was washed out of the soil into the drains or into the underground water supply by heavy rain. Losses of nitrate nitrogen equal to several hundreds of pounds of nitrate of soda per acre at least were indicated.

It would appear of great interest to see what happens to the nitrate which is washed out of the surface soil. This matter has not received much attention hitherto. It is frequently stated that practically no denitrification takes place in soils. If this nitrate is accumulated in the subsoil water one would expect to find enormous stores of nitrate down below. Large accumulations of nitrates in the soil are, however, rare, the best known example being, of course, the Chilean nitrate deposits. But the conditions under which these deposits have accumulated are peculiar and are seldom met with.

It was considered that a study of the levels and chemical composition of the water in wells throughout the year should give results of interest in this connection. An intimate study of two wells on the Agricultural College Farm, Nagpur, was commenced in June 1925. The investigation has been carried on continuously since that date. The wells are about 200 yards apart and are sunk in the black cotton soil. One we have called "Students' well" and the other "Alkaline well". The former is 627″ from soil level to the bottom and the latter only 507″ and both just reach the trap rock. The former has not been used for many years and has a tile drain discharging into it and thus we were able to form an idea of the rate of nitrification in the surrounding soil. The latter well is used to a certain extent for irrigation and the land around has received heavy dressings of cattle manure and artificials for some years. Moreover, the area surrounding this well is also underdrained with tile drains and hence we are able to analyse the drainage water from this area also. The depth of water was determined at frequent intervals and always when any change in water level took place. On every such occasion, the water was analysed for total solids, nitrate content and usually for bicarbonates and carbonates and occasionally gravimetric estimations were made of the calcium, magnesium and sulphate contents. It was quite early recognised that the composition of the water was not always uniform at different levels and soon after the experiment started each well was always sampled at 3 different levels, bottom, middle and top. These samples were taken in a weighted bottle, the stopper of which could be opened by a string at any desired level.

The nitrate was determined by the phenoldisulphonic acid method as in Part I. *Tables VI and VII give the data obtained for well levels, total solids and nitrate content of the two wells under observation.*

From August 1925 onwards, the samples were drawn from 3 different levels, bottom, middle and top. The bracketed figures give the analyses in this order.

The rainfall during the period under observation has already been given in part I of this paper. The rainfall data, well levels and nitrate content of the wells have been plotted in Chart No. III.

Consideration and discussion of results.

I. General observations on well levels and nitrate content.

At the beginning of the rains in June 1925, the students' well had a depth of 400″ of water and the alkaline well of 280″.

TABLE VI.

Students' well.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
1	22nd June 1925	238″	69·5	0·010	0·22
2	29th " "	238″	68·8	0·024	0·50
3	7th July "	238″	68·4	0·020	0·42
4	13th " "	172″	60·2	0·072	1·76
5	15th " "	166″	50·3	0·080	1·98
6	20th " "	165½″	45·8	0·088	2·16
7	27th " "	162″	51·4	0·095	2·35
8	3rd August "	139″	45·6	0·110	2·85
9	10th " "	106″	49·1	0·13	3·60
10	17th " "	76″	45·8	0·13	3·80
11	28th " "	49″	64·2 56·5 45·8	0·00 0·05 0·09	1·53
2	31st " "	43″	63·3 60·6 46·8	0·02 0·01 0·09	1·24

TABLE VI—*contd.*

Students' well—contd.

S. No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Parts per 100·000 Nitrate N as N	Total lb. of $NaNO_3$ in well
13	7th September 1925 . . .	48″	62·1 58·0 46·4	0·02 0·03 0·03	0·83
14	15th ,, ,, . . .	69″	58·8 68·5 48·9	0·02 0·05 0·05	1·23
15	21st ,, ,, . . .	80″	56·2 60·0 48·1	0·02 0·02 0·03	0·72
16	28th ,, ,, . . .	87″	62·6 56·9 47·7	0·02 0·02 0·02	0·66
17	5th October ,, . . .	95″	63·2 56·2 48·1	0·03 0·03 0·03	0·85
18	12th ,, ,, . . .	102″	62·32 56·24 49·36	0·01 0·01 0·01	0·37
19	19th ,, ,, . . .	108″	61·28 53·20 50·56	0·02 0·01 0·01	0·39
20	26th ,, ,, . . .	116″	54·40 55·60 55·60	0·02 0·02 0·01	0·43
21	2nd November ,, . . .	121″	55·92 54·80 55·52	0·01 0·01 0·01	0·47
22	9th ,, ,, . . .	126″	55·20 54·64 54·16	0·01 0·01 0·01	0·31
23	17th ,, ,, . . .	130″	52·08 54·80 54·32	0·01 0·01 0·01	0·40
24	23rd ,, ,, . . .	131″	54·32 55·20 54·16	0·01 0·01 0·01	0·40
25	30th ,, ,, . . .	134″	56·48 54·96 55·44	0·02 0·02 0·02	0·59

TABLE VI—*contd.*

Students' well—contd.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
26	7th December 1925	139″	60·48 62·96 58·40	0·02 0·02 0·02	0·052
27	14th " "	141″	55·28 55·28 54·80	0·03 0·02 0·02	0·071
28	21st " "	145″	55·44 54·80 53·60	0·02 0·01 0·01	0·047
29	28th " "	148″	56·40 55·76 56·00	0·02 0·02 0·02	0·57
30	5th January 1926	149″	55·60 57·76 52·08	0·02 0·02 0·02	0·051
31	11th " "	153″	54·80 54·80 54·72	0·02 0·02 0·02	0·05
32	18th " "	154″	56·48 55·60 54·80	0·03 0·02 0·02	0·067
33	25th " "	160″	57·04 55·84 55·20	0·01 0·01 0·01	0·415
34	1st February "	163″	57·60 56·08 57·36	0·02 0·02 0·02	0·64
35	10th " "	168″	55·44 55·20 55·84	0·01 0·01 0·01	0·43
36	15th " "	170″	55·28 55·68 56·00	0·02 0·02 0·02	0·61
37	22nd " "	173″	54·80 54·64 55·20	0·02 0·02 0·02	0·558
38	1st March "	176″	55·84 55·52 56·00	0·02 0·02 0·02	0·46

TABLE VI—*contd.*

Students' well—contd.

S. No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Parts per 100·000 Nitrate N as N	Total lb. of $NaNO_3$ in well
39	10th March 1926	180″	56·56 56·72 56·08	0·12 0·12 0·02	0·47
40	15th „ „	182″	56·88 56·80 57·76	0·01 0·01 0·01	0·39
41	24th „ „	186″	57·60 56·96 56·96	0·02 0·02 0·02	0·55
42	29th „ „	188″	57·04 57·20 56·88	0·01 0·01 0·01	0·39
43	6th April „	192″	58·24 58·08 57·76	0·01 0·01 0·01	0·37
44	12th „ „	194″	57·44 56·08 58·96	0·01 0·01 0·01	0·35
45	19th „ „	197″	57·12 57·92 57·52	0·01 0·01 0·01	0·34
46	24th „ „	201″	57·76 58·24 58·00	0·01 0·01 0·01	0·34
47	3rd May „	204″	58·72 60·80 59·76	0·007 0·007 0·010	0·19
48	10th „ „	206″	58·16 57·92 58·88	0·01 0·01 0·01	0·22
49	17th „ „	208″	58·00 57·68 59·52	0·00 0·00 0·00	0·00
50	19th „ „	208″	58·48 57·68 59·28	*Nil*	*Nil*
51	28th „ „	210″	58·24 58·38 58·96	„	„

TABLE VI—*contd.*

Students' well—contd.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
52	2nd June 1926 . . .	212″	58·08 56·00 59·60	*Nil*	*Nil*
53	8th " " . . .	215″	59·36 59·76 61·60	"	"
54	16th " " . . .	217″	60·16 60·22 62·40	"	"
55	23rd " " . . .	218″	61·12 60·56 61·52	"	"
56	29th " " . . .	220″	61·52 61·52 62·96	"	"
57	6th July " . . .	212″	61·60 60·56 59·36	"	"
58	12th " " . . .	187″	58·64 57·84 50·08	0·11	0·82
59	26th " " . . .	162″	63·28 57·92 47·84	0·00 0·00 0·09	0·74
60	3rd August " . . .	149″	58·00 57·28 46·00	0·01 0·01 0·04	0·64
61	10th " " . . .	109″	50·80 48·08 40·00	0·07 0·09 0·02	0·30
62	17th " " . . .	84″	51·12 49·28 41·60	0·06 0·09 0·15	2·94
63	25th " " . . .	60″	49·44 47·84 43·60	0·08 0·08 0·10	2·61
64	3rd September " . . .	51″	55·60 47·68 43·20	0·04 0·07 0·10	2·23

TABLE VI—*contd.*

Students' well—contd.

S. No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Parts per 100·000 Nitrate N as N	Total lb. of $NaNO_3$ in well
65	9th September 1926	58″	48·32 45·04 43·44	0·04 0·05 0·04	1·29
66	15th " "	60″	46·32 47·92 43·28	0·03 0·02 0·02	0·81
67	21st " "	68″	47·76 50·08 45·12	0·04 0·04 0·06	1·51
68	1st October "	84″	47·36 48·08 45·12	0·04 0·04 0·05	1·38
69	9th " "	84″	51·52 50·48 44·64	0·02 0·02 0·03	0·75
70	15th " "	97″	53·52 47·68 47·52	0·02 0·04 0·04	0·96
71	23rd " "	99″	50·72 55·28 51·04	0·005 0·005 0·005	0·14
72	29th " "	108″	50·72 51·28 51·04	*Nil*	*Nil*
73	3rd November "	109″	51·36 50·88 50·80	"	"
74	13th " "	118″	50·48 51·52 50·40	0·012 0·017 0·020	0·44
75	20th " "	124″	51·60 52·00 51·12	0·02 0·017 0·017	0·39
76	26th " "	128″	51·60 50·56 50·96	0·017 0·015 0·015	0·42
77	4th December "	133″	51·44 52·96 50·72	0·012 0·012 0·012	0·32

TABLE VI—*concld.*

Students' well—concld.

S. No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Nitrate N as N	Total lb. of $NaNO_3$ in well
78	11th December 1926	141″	52·24 51·36 51·36	0·012 0·012 0·012	0·32
79	18th ,, ,, ...	140″	51·68 51·76 50·88	0·012 0·012 0·012	0·28
80	24th ,, ,, ...	144″	54·00 55·36 55·12	0·012 0·007 0·005	0·21

TABLE VII.

Alkaline well.

S. No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Nitrate N as N	Total lb. of $NaNO_3$ in well
1	22nd June 1925	224″	77·6	0·22	3·52
2	29th ,, ,, ...	224″	77·8	0·14	2·26
3	13th July ,, ...	193″	76·0	0·12	2·09
4	15th ,, ,, ...	178″	74·9	0·10	1·90
5	20th ,, ,, ...	144″	75·6	0·08	1·61
6	27th ,, ,, ...	128½″	76·0	0·22	4·60
7	3rd August ,, ...	93½″	74·40 74·24 74·40	0·21 0·21 0·20	4·80
8	10th ,, ,, ...	66½″	68·40	0·19	4·63
9	17th ,, ,, ...	62″	65·52	0·19	4·68
10	19th ,, ,, ...	56″	75·44 73·76 66·32 65·44 63·20 63·60	0·17 0·17 0·17 0·17 0·17 0·17	4·24

TABLE VII—*contd.*

Alkaline well—contd.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
11	21st August 1925	60″	74·80 72·24 64·64	0·14 0·18 0·16	3·96
12	24th ,, ,, ...	50″	70·56 68·68 68·04	0·12 0·12 0·12	3·03
13	31st ,, ,, ...	57″	69·12 68·56 65·44	0·11 0·11 0·10	2·66
14	7th September ,, ...	66″	68·56 68·88 68·16	0·12 0·12 0·10	2·76
15	15th ,, ,, ...	88″	68·96 50·80 69·16	0·03 0·05 0·10	1·39
16	21st ,, ,, ...	94″	68·96 66·40 66·00	0·03 0·06 0·01	0·75
17	28th ,, ,, ...	87″	69·28 67·52 66·24	0·05 0·03 0·08	1·23
18	5th October ,, ...	98″	67·84 67·60 67·28	0·04 0·06 0·07	1·29
19	12th ,, ,, ...	107″	69·12 61·12 69·24	0·017 0·02 0·02	0·48
20	19th ,, ,, ...	107″	80·00 58·24 67·04	0·032 0·030 0·030	0·68
21	26th ,, ,, ...	137″	74·16 70·64 73·04	0·15 0·15 0·15	3·12
22	2nd November ,, ...	153″	74·72 73·76 72·72	0·10 0·10 0·10	2·05
23	9th ,, ,, ...	154″	74·56 75·04 75·04	0·22 0·21 0·22	4·23

TABLE VII—*contd.*

Alkaline well—contd.

S No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Parts per 100·000 Nitrate N as N	Total lb. of $NaNO_3$ in well
24	17th November 1925 . . .	129″	74·22 74·96 73·04	0·22 0·22 0·23	4·66
25	23rd ,, ,, ...	123″	75·36 74·48 75·52	0·22 0·22 0·24	4·73
26	30th ,, ,, ...	159″	76·32 75·84 77·28	0·26 0·26 0·26	5·00
27	7th December ,, ...	159″	87·44 76·16 72·08	0·32 0·31 0·30	5·96
28	14th ,, ,, ...	149″	76·08 76·56 76·72	0·36 0·34 0·34	6·86
29	21st ,, ,, ...	155″	65·28 70·00 73·60	0·30 0·32 0·32	6·08
30	28th ,, ,, ...	149″	76·92 75·04 72·80	0·32 0·30 0·30	6·07
31	5th January 1926 . . .	151″	83·44 68·56 75·04	0·36 0·40 0·40	7·65
32	11th ,, ,, ...	153″	75·68 69·44 74·88	0·34 0·34 0·32	6·45
33	18th ,, ,, ...	154″	75·92 77·92 75·60	0·44 0·42 0·42	8·33
34	25th ,, ,, ...	167″	74·40 76·80 78·24	0·30 0·44 0·44	7·38
35	1st February ,, ...	163″	76·80 76·08 76·24	0·42 0·42 0·42	7·98
36	10th ,, ,, ...	167″	75·68 75·36 75·92	0·34 0·32 0·32	6·13

TABLE VII.

Alkaline well.

S. No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Parts per 100·000 Nitrate N as N	Total lb. of $NaNO_3$ in well
37	15th February 1926 . .	185″	75·36 75·56 77·52	0·44 0·44 0·44	7·82
38	22nd „ „ . . .	172″	75·68 75·84 77·80	0·42 0·42 0·42	7·76
39	1st March „ . . .	182″	76·32 76·96 77·20	0·40 0·40 0·40	7·17
40	10th „ „ . . .	185″	76·24 76·32 76·32	0·34 0·34 0·36	6·16
41	15th „ „ . . .	190″	77·44 77·44 78·16	0·32 0·32 0·32	5·59
42	23rd „ „ . . .	185″	77·20 75·20 76·80	0·28 0·30 0·30	4·62
43	29th „ „ . . .	208″	77·44 77·12 78·00	0·22 0·24 0·24	3·84
44	6th April „ . . .	204″	77·52 78·32 78·64	0·24 0·28 0·28	4·12
45	12th „ „ . . .	193″	79·12 79·04 80·96	0·22 0·24 0·24	4·03
46	19th „ „ . . .	197″	77·44 76·96 78·32	0·18 0·20 0·20	3·30
47	24th „ „ . . .	208″	77·12 77·12 77·36	0·28 0·28 0·28	4·61
48	3rd May „ . . .	207″	78·24 78·24 77·68	0·24 0·24 0·24	3·97
49	10th „ „ . . .	206″	77·04 77·04 76·88	0·24 0·24 0·24	3·98

TABLE VII.

Alkaline well.

S. No.	Date	Depth of water below ground level	Parts per 100·000 Total solids	Parts per 100·000 Nitrate N as N	Total lb. of $NaNO_3$ in well
50	17th May 1926 . . .	248″	76·72 76·16 76·24	0·24 0·28 0·28	3·80
51	19th ,, ,, . . .	220″	75·28 74·96 75·28	0·32 0·32 0·32	5·06
52	28th ,, ,, . .	222″	77·12 75·92 76·00	0·26 0·30 0·30	4·50
53	2nd June ,, . . .	225″	74·88 74·00 75·46	0·24 0·30 0·30	4·35
54	8th ,, ,, . . .	215″	75·68 74·24 75·92	0·22 0·29 0·29	4·30
55	16th ,, ,, . . .	240″	76·40 73·28 75·28	0·34 0·36 0·34	5·09
56	23rd ,, ,, . . .	268″	77·74 76·08 74·96	0·26 0·34 0·34	4·13
57	29th ,, ,, . . .	255″	77·04 75·20 74·64	0·32 0·46 0·46	5·74
58	6th July ,, . . .	216″	74·24 72·88 72·32	0·44 0·44 0·44	7·06
59	13th ,, ,, . . .	151″	73·52 72·80 71·68	0·44 0·44 0·44	8·65
60	26th ,, ,, . . .	117″	74·40 75·44 75·32	0·34 0·36 0·40	7·91
61	3rd August ,, . . .	123″	74·96 72·88 72·40	0·30 0·40 0·40	7·79
62	10th ,, ,, . . .	69″	72·40 71·44 70·00	0·42 0·48 0·44	10·83

TABLE VII.

Alkaline well.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
63	17th August 1926 . . .	60″	71·36 69·92 71·00	0·40 0·39 0·39	9·72
64	25th „ „ . . .	$62\frac{1}{2}$″	69·60 68·88 68·40	0·28 0·28 0·28	6·88
65	3rd September „ . .	60″	68·96 67·20 65·92	0·24 0·24 0·24	5·94
66	9th „ „ . . .	65″	68·40 70·80 69·52	0·29 0·29 0·29	7·09
67	15th „ „ . . .	65″	66·64 66·72 65·92	0·22 0·22 0·22	5·38
68	21st „ „ . . .	76″	66·96 65·12 66·08	0·20 0·20 0·20	4·77
69	1st October „ . . .	103″	71·36 69·20 68·32	0·19 0·19 0·19	4·24
70	9th „ „ . . .	90″	71·84 68·64 68·48	0·14 0·14 0·14	3·23
71	15th „ „ . . .	95″	71·52 69·28 69·04	0·14 0·15 0·12	3·12
72	23rd „ „ . . .	117″	70·22 71·28 69·44	0·13 0·13 0·13	2·80
73	29th „ „ . . .	177″	73·52 75·20 75·44	0·24 0·22 0·20	4·01
74	3rd November „ . . .	157″	73·52 73·68 73·60	0·30 0·30 0·30	5·80
75	13th „ „ . . .	143″	73·44 75·68 76·24	0·32 0·32 0·32	6·43

TABLE VII.

Alkaline well.

S. No.	Date	Depth of water below ground level	Parts per 100·000		Total lb. of $NaNO_3$ in well
			Total solids	Nitrate N as N	
76	20th November 1926	137″	75·04 74·72 74·56	0·36 0·34 0·34	7·09
77	26th ,, ,, . . .	157″	76·00 76·72 75·28	0·38 0·36 0·36	7·09
78	4th December ,, . . .	151″	75·6 74·32 75·04	0·34 0·34 0·34	6·60
79	11th ,, ,, . . .	155″	76·0 76·96 75·6	0·34 0·34 0·34	6·61
80	18th ,, ,, . . .	153″	75·44 74·96 74·96	0·40 0·40 0·40	7·82
81	24th ,, ,, . . .	161″	76·08 75·6 74·32	0·36 0·36 0·40	7·13

The former contained practically no nitrate, *viz.*, nitrate ·0105 parts nitrogen per 100,000 or 0·218 lb. $NaNO_3$ in the whole well. The latter well was fairly rich in nitrate, *viz.*, 0·226 parts of nitrogen per 100,000 or 3·52 lb. $NaNO_3$ in the whole well. With the first rapid rise of both wells about the 7th July, the former increased in nitrate content and the latter lost nitrate and by mid July the total nitrate content was about equal in the two wells. The nitrate content then increased in both. In the case of the Alkaline well, it rose almost to its highest point abruptly at the end of July when it contained 4·6 lb. $NaNO_3$ in the whole well. It remained constant at about this level of nitrate content till mid August. The Students' well showed a gradual rise in nitrate content and reached its maximum content of 3·8 lb. $NaNO_3$ just after mid August. The more abrupt rise in nitrate content of the Alkaline well was accompanied by a more abrupt rise in the well level than occurred in the case of the Students' well. It is probable that this difference in rapidity of rise between the two wells is due to the fact that the soil surrounding the Alkaline well was irrigated during the dry weather. Water would percolate more rapidly through this moist soil than it would through the drier unirrigated soil surrounding the Students' well.

Both wells reached their highest water level in the last week of August, but from the 3rd week of August a steady fall in nitrate content began and each well contained only about ½ lb. $NaNO_3$ by mid October. The levels of both wells began falling steadily from the beginning of September. The Students' well never again recovered its nitrate content and in May 1926 it contained not a trace of nitrate. At the end of October, however, the nitrate content of the Alkaline well began to rise steadily and throughout the cold weather 1925-26 it contained more nitrate than at any time during the preceding rains. Early in November it contained 4·2 lb. of $NaNO_3$ or nitrate nitrogen =·22 parts of nitrogen per 100,000, and on January 1st, 1926 it contained 8·33 lb. of $NaNO_3$ or nitrate =·44 parts of nitrogen per 100,000. The rise in nitrate content of this well in the cold weather must be ascribed to the fact that it was used for irrigation of the surrounding land during that period. This irrigation water circulated through the soil back to the well. Rapid nitrification took place on this moist soil and the excess nitrates were, of course, washed back into the well. That there were large accumulations of nitrate in the cold weather of 1925-26 was proved by the fact that there was a sudden flow of the tile drains in this area on November 9th, following a 1½″ fall of rain and this drainage water was exceedingly rich in nitrate. The results obtained from these two wells in 1926 were similar to those of the previous year. The rise of well level early in the rains was again more abrupt in the case of the Alkaline well than in that of the Students' well. It is remarkable, however, that during the rains of 1926 the Alkaline well was much richer in nitrate than during the previous rainy season. Thus in the rains of 1926 it reached the maximum $NaNO_3$ content of 10·8 lb. and from 6th July to 25th August never fell below 7 lb. of $NaNO_3$, whereas during the rains of 1925 it only contained a maximum of 4·6 lb. The Students' well, however, reached a maximum content of only 3·3 lb. during the rains of 1926 as against 3·8 lb. in the previous rainy season and generally appeared to contain less nitrate throughout the rainy season of 1926 than in 1925. Moreover, in 1926 it had lost all its nitrate by the end of October, whereas in the previous season it contained small amounts of nitrate throughout the cold weather and up to May 1926. Small amounts of nitrate were, however, found in this well subsequent to October 1926. It is difficult to find a reason for the difference in behaviour of these two wells in two succeeding seasons. To a certain extent, the year 1926 was exceptional in that there was a fall of about 6″ of rain in the 3rd week of May. This may have encouraged nitrification on the highly manured soil around the alkaline well to a greater extent than on the unmanured soil round the Students' well.

Before leaving this question of well levels, it will be of interest to draw attention to the fluctuations which occur in the level of the Alkaline well as compared with the level of the Students' well. This is well seen in the Chart and it is only necessary to remark that the fluctuations in level corresponded to the periods during which the Alkaline well was being used for irrigation.

2. Losses of nitrate from the well water.

It will be obvious from the Table and Chart that the nitrate which passes into the well water gradually disappears. The Students' well contained a maximum amount of 3·8 lb. of $NaNO_3$ in the rains of 1925. By May 1926 this had completely disappeared. The surface area of this well is 17·72 square yards. The loss of nitrate of soda per acre per year in the underground soil water which occurred on the unmanured area surrounding the Students' well may thus be taken to be $4840/17{\cdot}72 \times 3{\cdot}8$ or 1038 lb. In the rains of 1926 the loss observed was 3·3 lb. of $NaNO_3$ $= 4840/17{\cdot}72 \times 3{\cdot}3$ or 901 lb. $NaNO_3$ per acre. In the case of the manured land surrounding the Alkaline well, the losses would appear to be far greater. Thus on 3rd August 1925 this well contained 4·8 lb. of $NaNO_3$ and on 12th October it only contained 0·48 lb. of $NaNO_3$ a loss of 4·32 lb. of $NaNO_3$. The surface area of this well is 19 square yards, hence the loss per acre in 1925 was $4840/19 \times 4{\cdot}32$ or 1100 lb. of $NaNO_3$. Figures for the early part of the year 1925 are not available. On the 18th January 1926 this well again contained 8·33 lb. of $NaNO_3$ and on 19th April this amount had fallen to 3·3 lb. a loss of 5 lb. $NaNO_3 = 4840/19 \times 5$ or 1274 lb. $NaNO_3$ per acre. On 10th August 1926 this well again contained 10·83 lb. $NaNO_3$ and by 23rd October this figure had fallen to 2·80 a loss of 8 lb. $NaNO_3 = 4840/19 \times 8$ or 2037 lb. $NaNO_3$ per acre.

It thus appears that the unmanured unirrigated soil surrounding the Students' well annually loses nitrate equivalent to about 1000 lb. nitrate of soda per acre or say 165 lb. nitrogen. The irrigated highly manured soil surrounding the Alkaline well lost during the year 1926 nitrate equivalent to $1274 + 2037 = 3311$ lb. of $NaNO_3$ per acre or say 550 lb. of nitrogen. In making these calculations, we have assumed that the water table is a continuation of the well level throughout the subsoil and that the whole of this subsoil water suffers losses similar to those of the well water. This we consider a reasonable assumption. If it were not the case, one would not expect the *complete* disappearance of nitrate from the well and absence of nitrate for 6-7 weeks or more as we found in the case of the Students' well in May and June 1925 and again from the end of October 1926 to date of writing (January 1927). If the rest of the underground water contained nitrate, it would surely diffuse to some extent into the well.

These losses are enormously greater than have been observed elsewhere. Thus in the Broadbalk[1] field at Rothamsted the largest loss of nitrate nitrogen from any of the plots is computed to be about 78 lb. annually. This was from a plot receiving minerals +400 lb. ammonium salts. The unmanured plot was computed to have lost less than 18 lb. nitrate nitrogen. However, these figures are but a rough estimate since the amount of water passing into the subsoil was not accurately measured but was in part computed from the flow through the drain gauges. Batham[2] in work on the drain gauges at Cawnpore found an average annual loss from

[1] The Book of the Rothamsted Experiments, Hall & Russell, p. 235, 1919.
[2] *Mem. Dept. Agri. India, Chem. Ser.*, VIII, No. 8, p. 138, 1926.

the 6-foot drain gauge during 1905-09 of 81 lb. nitric nitrogen per acre. In subsequent years the loss was much less. At Cornell U.S.A. it was found that 69 lb. of nitric nitrogen equivalent to 419 lb. of $NaNO_3$ were washed out of uncropped soil annually[1].

Hence it appears that either the losses of nitrate nitrogen from the soil at Nagpur are much higher than at Rothamsted, Cawnpore and Cornell or else the figures recorded for these 3 latter places are low.

A reference to Part I of this paper (p. 173) shows that in our work on the nitrate content of the soil a minimum annual loss of approximately 80 and 104 lb. of nitrate nitrogen was observed in 1925 on unmanured and manured soil respectively. For reasons there stated these figures must be on the low side.

3. *Variation in composition of well water at different depths.*

The necessity was early recognised of sampling the well water at different depths. Since August 1925 both wells were always sampled (*a*) near the bottom (*b*) half way up (*c*) just below the surface. A consideration of the analyses made at these different depths brings out points of great interest. It will perhaps be best to consider in detail only the results for the season 1926 since the sampling at 3 different depths in 1925 began late. It will be seen, however, that in general the 1925 figures where available support our general remarks on the 1926 figures.

A study of these figures shows that the 2 wells behave differently. The alkaline well shows at each sampling a uniform content of total solids at each depth on almost every occasion. As will be seen in the next paragraph, the total solid content of this well water shows only a small variation throughout the year and it would seem that the distribution of salts throughout the soil and well water has reached a condition of equilibrium so that the percolate into the well always has a more or less uniform content of total solids in solution. As regards the Students' well, it will be seen that on 13th July 1926 the first rapid rise of water level took place. Previous to that date, the total solid content of the 3 different depths sampled was approximately constant at about 60 parts per 100,000. On the 13th July, however when the rise took place the bottom layer contained 58·64 parts of total solids per 100,000 and the top layer only 50 parts. This difference in composition was maintained on each subsequent season in which the well was sampled until 3rd September 1926 after which date the well level began to fall and then the total solid content at each level became uniform. It is obvious that in the case of this well the percolate through the soil is less concentrated in total salts than the well water itself.

As regards the nitrate content at the different depths, it will be seen that in the case of the Students' well before the 13th July 1926 there was no nitrate in the well water and when the level began to rise on 13th July a considerable amount of nitrate was found in the surface layer and only minute traces at lower depths. From that date onwards until 3rd September, the surface layer of the well always con

[1]Nature and Properties of Soils, Lyon and Buckman, p. 208.

tained most nitrate, but after that date when the level began to fall and no more percolation took place into the well, the nitrate was more or less uniformly distributed at each depth.

In the case of the alkaline well the nitrate content of the water at each depth is more or less uniform at each sampling though there are occasional indications that the top layer is richer than the lower depths, *e.g.*, in the analyses made in September and early October 1925.

4. Seasonal changes in the total solid content of the wells.

As mentioned in the previous section the two wells show a well marked difference when considered from the point of view of their total solid content at different seasons of the year. The alkaline well varies remarkably little in total solid content of its water throughout the year. In the hot dry weather when the well is at its lowest level, the water contains about 75·78 parts of total solids per 100,000. During the rains it contains rather less, *viz.*, 66·70 parts per 100,000. The Students' well, however, shows a remarkable difference in its total solid content at different seasons. During the cold weather and early hot weather its total solid content varies from 55-60 parts per 100,000. Immediately before the rains at the end of the hot weather the total solid content shows a slight tendency to increase, but when the well begins to rise it is obvious that the water percolating into it contains much less solid matter than the well water itself and by September the well water contains only 43 to 47 parts of total solids per 100,000. In the case of the Students' well it would also appear that the total solid content of the water was distinctly higher in the hot weather of 1925 than in that of 1926, whereas there was no such difference in the case of the Alkaline well. As the hot weather advances there appears to be a distinct tendency towards concentration of the water in the Students' well, but no such tendency in the case of the Alkaline well.

The cause of the difference between these two wells must be ascribed to the fact that the Alkaline well has been used for irrigation for years past and is used regularly throughout the cold weather and hot weather. There is thus continual circulation of water down through the soil and into the well, and there is a tendency for the soil water and the well water to become uniform in composition. On the other hand, the Students' well is never used for irrigation and during the hot weather there is distinct concentration by evaporation at the water surface.

It is of interest to point out here that the irrigated area surrounding the Alkaline area only measures half an acre and since there is such little change in the composition of the well water it would appear that very little lateral diffusion of the subsoil water takes place.

5. Carbonate and bicarbonate of soda contents in the well waters.

The two wells have been regularly analysed for carbonate and bicarbonate, but it is hardly worth while burdening this paper with the complete figures obtained. It is sufficient to say that the total solids consist mainly of sodium bicarbonate

with a small amount of normal sodium carbonate. As regards chlorides, sulphates, lime and magnesia, their quantities are small, as shown in the following analysis carried out on 9th September 1926 :—

Well	Position in well	Total solids	Parts per 100,000.			Cl.
			SO_3	CaO	MgO	
Alkaline well	Bottom	68·4	2·55	2·52	3·57	1·48
	Middle	70·8	1·81	2·60	3·49	1·58
	Top	69·5	2·63	3·12	3·58	1·62
Students' well	Bottom	48·3	1·95	2·04	1·01	1·72
	Middle	45·0	1·34	1·88	0·86	1·72
	Top	43·4	1·48	1·64	0·91	1·62

Analyses made in June 1925 gave substantially the same figures.

The question of the form in which the nitrate is washed out of the soil becomes interesting. If it were washed out as nitrate of calcium one would have expected to find large amounts of calcium in the water. As a matter of fact the water is poor in lime. It seems that the nitrate must be washed out as nitrate of soda. It is therefore suggested that when this compound denitrifies, sodium carbonate and sodium bicarbonate are formed. It is significant that the well which has been used most regularly for irrigation contains most bicarbonate and carbonate. This also is the well which suffers the largest loss of nitrate.

Hall[1] has shown that sodium carbonate is formed in the soil from sodium nitrate under certain conditions. The point is interesting on irrigated soils in a hot climate because if a well is used for irrigation the continual percolation of the well water throughout the soil and back to the well must eventually result in an accumulation of sodium carbonate in the soil. It will be of interest to recall that a few years ago when there was a shortage of water in Nagpur, certain members of the Agricultural Department utilized the water of the Alkaline well to water plants in pots and they were killed.

General bearing of the results on the maintenance of fertility in black cotton soil.

We have shown above how enormous are the losses of nitrate nitrogen from the soil at Nagpur.

On unmanured unirrigated soil this loss is approximately equal to 1,000 lb. of nitrate of soda or say 160 lb. of nitrogen. On well-irrigated highly manured soil the loss appears to be more than 3 times as great as this. However, it is unlikely that any soil in the Central Provinces receives such abnormal dressings of manure as have been applied to the land on which these figures were obtained and since moreover irrigation is not practised in the soil on which we are working we will only consider the unmanured unirrigated soil.

[1] The Book of the Rothamsted Experiments, 1919, Hall and Russell, p. 300.

Assuming, therefore, that a loss of 160 lb. of nitrate nitrogen annually takes place from unmanured unirrigated soil, it will be of interest to calculate in how many years the soil will become completely exhausted of nitrogen. It is usually assumed that nitrification takes place only in the top 9″ of soil in England, *i.e.*, the cultivated portion. In India the cultivated portion may be assumed to be not more than 6″ in depth and our figures and Charts in Part I of this paper indicate that most if not all nitrification takes place in this portion. The weight of an acre of black cotton soil 6″ deep may be taken as roughly 1,500,000 lb. This contains roughly ·05 per cent or 7,500 lb. of nitrogen. Since the annual loss from the soil of nitrate nitrogen amounts to about 160 lb. the top 6″ of soil should be entirely depleted of nitrogen in 7500/160=say 47 years. From a comparison of analyses by Dr. Leather made on the same soil 25 years ago with those made by us recently, the soil appears to have suffered no loss in total nitrogen during that period. It can only be assumed therefore that fixation of atmospheric nitrogen is taking place to a large extent in black cotton soil. It is also of interest to observe that the nitrogen content of the soil remains nearly constant from year to year and that therefore some kind of physiological nitrogen balance must be maintained in the soil. This is probably due to the fact that the conditions favouring nitrification also favour nitrogen fixation.

However, if these large losses and gains of nitrogen are taking place in the soil one would expect to find distinct variations in the total nitrogen content of the soil at different periods of the year. In order to test this many hundreds of determinations of total nitrogen have been carried out both on the unmanured and manured plots. There is no object in burdening this paper with a mass of figures but it will be sufficient to give a few figures showing the variation in total nitrogen content of the soil from time to time.

Total nitrogen content of the soil at various periods.

Date	%N. in dry soil.			
	Unmanured plot		Manured plot	
	0-6″	6-12″	0-6″	6-12″
1st July 1925	·060	·059	·071	·059
3rd August 1925	·054	·051	·058	·055
23rd September 1925	·064	·060	·058	·055
7th October 1925	·053	·052	·071	·063
25th November 1925	·067	·066	·066	·056
3rd February 1926	·051	·047	·055	·049
31st March 1926	·061	·051	·056	·048
30th April 1926	·057	·053	·066	·055
4th June 1926	·069	·052	·067	·053
30th June 1926	·075	·052	·062	·050
19th July 1926	·059	·064	·077	·069
24th August 1926	·071	·053	·065	·060
16th September 1926	·094	·049	·080	·050
21st October 1926	·066	·052	·072	·051
29th November 1926	·061	·047	·059	·048

These figures indicate that there are considerable variations in the nitrogen content of the soil from time to time.

However, there are distinct differences in the nitrogen content of the soil of different parts of a plot on the same day. This is shown in the next Table.

Plot	Depth	Per cent nitrogen in the samples from different portions of the same plot — Sample number 1	2	3	4
I	0-6″	·065	·064	·059	·070
	6-12″	·055	·052	·051	·051

These differences, however, are not as great as those which occur at different periods of the year.

In the next Table are set out figures showing the results for total nitrogen estimation carried out in quadruplicate from the same soil sample. In one case the soil was passed through a 3 mm. sieve before weighing out the portions for analyses and in the other case it was not sieved.

—	Per cent nitrogen in quadruplicate determination on the same soil — Analysis number 1	2	3	4
Soil sieved	·065	·066	·070	·068
Soil unsieved	·062	·063	·061	·063

It is, we think, clear therefore that the variations in nitrogen content of the soil from different parts of the same plot on the same day and on the same plot at different periods of the year are real variations inasmuch as they are much greater than the experimental error involved in the method of analysis.

PART III.

OBSERVATIONS ON THE DRAINAGE WATERS FROM TILE DRAINED AREAS.

The plots which have been described as under experiment in Part I of this paper are all underdrained at a depth of 2′ 6″ by tile drains and the outfalls are so arranged that the drainage from each plot can be collected separately.

The highly manured irrigated area surrounding the alkaline well is also similarly underdrained. As already mentioned, the Students' well has a tile drain discharging into it which drains an unmanured unirrigated area. These drains of course, do not allow of any quantitative measure of the drainage since it would be impossible to collect the drainage of the whole areas drained. The concentration of the drainage water in nitrate, however, provides some indication of the amount of nitrate present in the soil throughout the rainy season which is the only period at which any drainage normally takes place. In the case of the irrigated area surrounding the Alkaline well, a certain amount of drainage was observed during the cold weather, but this will be referred to later.

The following Table gives the dates on which drainage took place from the drains under observation, together with the nitrate content of the drainage water. The data relate to the following areas :—

(*a*) Unmanured cropped plot.
(*b*) Manured cropped plot.
(*c*) Manured uncropped plot.
(*d*) Drain from unmanured area into Students' well.
(*e*) Drain from alkaline area around Alkaline well.

(*a*), (*b*) and (*c*) are the plots (3), (4) and (2) respectively referred to on page 158 under period (*b*). In the year 1925 data for the manured uncropped plot were not available and also the data for plots (*a*) and (*b*) are incomplete as considerable trouble was experienced with broken drain pipes under those plots in that year. The drains were repaired before the season of 1926 however.

TABLE VIII.

Nitrate nitrogen parts per 100,000 in drainage water.

1925.

Date	Drain in alkaline area	Drain in Students' well	Unmanured plot cropped	Manured plot cropped	Manured plot uncropped
July 7th . .	..	0·71	..	..	..
,, 8th . .	..	..	0·74	1·16	..
,, 10th . .	2·01	..	0·26	1·93	..

TABLE VIII.

Nitrate nitrogen parts per 100,000 in drainage water.
1925.

Date		Drain in alkaline area	Drain in Students' well	Unmanured Plot cropped	Manured Plot cropped	Manured Plot uncropped
July	11th . .	1·55	..	..	..	..
,,	13th . .	8 a.m. 1·93 3 p.m. 1·77	0·19	..	1·61	..
,,	14th . .	1·71	0·16	..	..	..
,,	15th . .	0·90	..	..	..	..
,,	17th . .	..	0·22	..	..	..
,,	18th . .	0·11	0·19	..	1·03	..
,,	20th . .	0·10	..	..	..	..
,,	23rd . .	0·08	0·16	..	..	..
,,	29th . .	8 a.m. 0·40 5 p.m. 0·52	0·12	..	0·12	..
,,	30th . .	0·64	0·20	..	..	..
,,	31st . .	0·68	0·24	..	..	..
August	1st . .	0·60	..	..	..	..
,,	3rd . .	0·40	..	..	..	..
,,	6th . .	0·07	..	..	..	..
,,	7th . .	8 a.m. 1·04 3 p.m. 0·96	0·41	..	..	..
,,	8th . .	0·80	8 a.m. 0·34 3 p.m. 0·80	..	..	..
,,	10th . .	0·48	0·24	0·10	0·20	..
,,	11th . .	8 a.m. 0·46 4 p.m. 0·56	0·26	..	..	..
,,	13th . .	0·28	..	..	..	..
,,	14th . .	0·18	..	..	..	..

TABLE VIII.

Nitrate nitrogen parts per 100,000 in drainage water.
1925.

Date	Drain in alkaline area	Drain in Students' well	Unmanured Plot cropped	Manured Plot cropped	Manured Plot uncropped
August 15th . .	0·08	..	..	..	..
„ 17th . .	8 a.m. 0·36 3 p.m. 0·24	..	0·30	0·21	..
„ 18th . .	0·30	..	..	..	..
„ 19th . .	0·28	..	..	..	..
„ 20th . .	0·26	..	..	..	..
„ 21st . .	0·21	..	..	..	..
„ 22nd . .	0·23	..	..	..	..
„ 24th . .	0·25	..	..	..	..
„ 25th . .	0·24	..	0·09	..	..
„ 26th . .	0·18	..	..	..	..
„ 27th . .	0·25	..	..	..	..
„ 31st .	0·26	..	0·05	0·14	..
September 1st .	0·24	..	..	..	..
„ 2nd . .	0·20	..	..	..	..
„ 3rd . .	0·20	..	0·06	..	..
„ 4th . .	0·16	..	..	..	..
„ 5th . .	0·15	..	..	..	..
„ 7th . .	0·04	..	..	..	..
„ 8th . .	0·02	..	..	..	..
„ 9th . .	0·00	..	..	..	..
„ 21st . .	0·29	..	..	..	..
„ 22nd . .	0·16	..	..	..	..
„ 23rd . .	0·09	..	..	..	..
November 10th . .	3·40	..	..	..	..

Table VIII.

Nitrate nitrogen parts per 100,000 in drainage water.

1925.

Date	Drain in alkaline area	Drain in Students' well	Unmanured plot cropped	Manured plot cropped	Manured plot uncropped
November 23rd . .	0·03	..	..	..	..
January 5th 1926 . .	1·20	..	..	..	..
No. of days on which drainage occurred . .	..	13	7	8	..
1926.					
July 10th . .	3·52	..	0·86	1·7	1·54
,, 12th . .	2·44	0·56	0·80	2·00	1·36
,, 13th . .	1·76	0·44	0·86	1·60	1·12
,, 14th . .	1·84	..	0·64	1·08	0·60
August 4th . .	1·60	0·90	0·42	0·32	0·42
,, 7th . .	1·38	0·40	0·28	0·40	0·64
,, 9th . .	0·80	0·22	0·16	0·18	0·34
,, 10th . .	0·72	0·20	0·12	0·18	0·24
,, 11th . .	0·56	0·22	0·07	0·10	0·19
,, 12th . .	0·48	0·22	0·07	0·07	0·20
,, 14th . .	0·64	..	..	..	..
,, 16th . .	0·52	0·18	0·08	0·04	0·22
,, 17th . .	0·42	..	0·09	0·06	0·11
,, 18th . .	0·16	0·03	0·02	0·02	0·04
,, 19th . .	0·40	..	0·07	0·09	0·15
,, 20th . .	0·72	..	0·05	0·08	0·18
,, 21st . .	0·28	..	0·04	0·04	0·10
,, 24th . .	0·40	..	..	..	..
,, 25th . .	0·22	..	..	..	..
,, 27th . .	0·28	..	0·03	0·04	0·07

TABLE VIII.

Nitrate nitrogen parts per 100,000 in drainage water.

1926.

Date	Drain in alkaline area	Drain in Students' well	Unmanured plot cropped	Manured plot cropped	Manured plot uncropped
August 28th . .	0·26	..	0·03	0·04	0·05
,, 30th . .	0·29	..	0·04	0·05	0·09
September 1st . .	0·24	..	0·02	0·06	0·05
,, 3rd . .	0·10	..	0·00	..	..
,, 10th . .	0·18	..	..	0·01	0·01
,, 13th . .	0·03	..	..	..	..
,, 14th . .	0·06	..	..	..	..
No. of days in which drainage occurred .	27	10	21	21	21

DISCUSSION OF RESULTS.

1. Number of days on which drains were running.

It will at once be obvious that the alkaline area gave much more drainage both in the years 1925 and 1926 than any other area. The table gives the number of days on which drainage occurred. In 1925 it is not fair to consider the unmanured and manured plots under this period since as was previously noted the drains gave trouble and on being opened up late in the rains were found to be broken. However, it will be seen that in the alkaline area the drains ran on 46 days during the period July 7th to January 5th, 1926. The drain in the Students' well only ran during 13 days and ceased altogether on 11th August. The small amounts of drainage received in August and September from the unmanured plots were almost certainly not true drainage but percolations from a ditch into the broken drain near the outfall.

It is quite obvious that drainage was much more regular from the alkaline area than from the area surrounding the Students' well. Also the former area continued to give drainage right through August and September. In November this area gave more drainage as a result of the effect of 2″ or 3″ of rainfall together with irrigations which were applied. There was a further flow of drainage from this area on the 5th January 1926, against the result of the combined effect of irrigation with a fall of just over an inch of rain.

In 1926 all the drains were in good order and hence we are able to consider all the five areas under experiment. The alkaline area again gave drainage on more days than any other area, but the difference was not so marked and in this season there was no flow after September 14th in spite of irrigation in early November and a fall of 0·64″ of rain in December. The difference between the two seasons is mainly due to the fact that in November 1925 the rainfall was 3·28″, whereas no rain fell at all in November 1926. The following Table gives the rainfall for July, August and September for the years 1925 and 1926 together with the number of days on which drainage was received on two of the areas :—

Year and month	Rainfall	No. of days on which drains ran	
		Alkaline well	Students' well
1925, July	15·50	11	9
1926, July	20·86	4	2
1925, August	23·43	21	4
1926, ,,	17·07	18	8
1925, September	3·76	11	..
1926, ,,	3·63	5	..
1925 { July, August, September	42·69	43	13
1926, ,,	41·56	27	10

It will be seen from this Table that the rainfall in the 2 years for these 3 months was practically the same, yet the drains ran far more often in 1925 than in 1926. Taking the month of July alone, the rainfall in 1925 was 5″ less than in 1926, yet the drains ran far more frequently in July 1925 than in July 1926. It is natural to assume that besides the total quantity of rain, the amount of individual falls is an important factor in determining the quantity of drainage.

If the falls are light, the soil is able to deal with them ; but if sudden falls occur, the water either scours the surface or percolates rapidly depleting the soil of nitrate. One of the beneficial effects of drains on land such as ours is that they enable it to deal more quickly with these excess falls of rain and to prepare the soil to protect itself better from the washing or scouring effects of any subsequent heavy falls.

The more frequent action of the drains on the alkaline area must be connected in some way with the fact that the soil is irrigated throughout the dry months. In consequence, it requires less rain to raise its water content to the point at which

drainage starts than does the unirrigated soil. However, once both soils had become saturated one would have expected both to behave similarly subsequently. It may be that in the unirrigated soil there are large fissures and that much of the water which could normally pass into the drains on a moist soil pass down these fissures to the subsoil water supply. It may be, of course, that the water table in the irrigated is nearer the surface than in unirrigated soil and thus would tend to cause the drains to flow more frequently by causing a certain amount of obstruction of the downward flow of water.

2. *The nitrate content of the drainage water.*

In the first place it will be noticed that when the drains first began to flow at the beginning of the rains the drainage was richer in nitrate than on any subsequent occasion. In the case of the richly manured alkaline area and the manured plot this richness in nitrate is maintained for some time longer than in the unmanured areas.

In the season 1925, it will be seen that after the middle of July the nitrate concentrations of the drainage water fell away rapidly on the alkaline area. On the 29th July there was a distinct recovery in the nitrate concentration of the drainage water. A reference to Table I and Chart I in Part I of this paper shows that this increase corresponds to a period when the nitrate content of the soil showed a sudden increase, see also remarks on page 172. There was a further recovery in the nitrate concentration of the drainage from the alkaline area on the 7th August. On the 10th November there was a flow from the drains under this area and this flow was exceedingly concentrated in nitrate. Nitrate estimations had not been carried out in the soil of this area, but it is evident that the irrigations carried out in October and early November together with cultivation in preparation for a cold weather crop had encouraged rapid nitrification. This is also borne out by the curves for nitrate content of the well on the alkaline area at this period (Part II), which shows a rapid rise in October and November. In the season 1926 the richly manured alkaline area and the manured areas again gave drainage much more concentrated in nitrate in the beginning of the rains than any of the other areas. In general, the nitrate content of the drainage water showed a steady falling off in every case as the season advanced. This is again evidence of the fact that nitrification is most active in our soils just at the beginning of the rains. The fact that the drainage from the alkaline area was throughout steadily richer than that from any of the other areas is further evidence that the alkaline area contains much greater stores of nitrate than any of the other areas under experiment.

As will be seen, the nitrate content of drainage waters found by us reached a maximum of 3·52 parts nitrogen per 100,000 on the richly manured alkaline area. On an area manured with only 4 tons of cattle manure per acre, the maximum nitrate concentration reached was 2 parts of nitrogen per 100,000 and in the unmanured plot 0·86 parts per 100,000. It will be of interest to compare our figures with the

maximum nitrate figures obtained at Rothamsted from the drains under Broadbalk plots. These are as follows[1] :—

Plot 3 unmanured	0·7	parts nitrogen per 100,000
Plot 7 Minerals sulphate of ammonia in spring . .	2·05	,, ,, ,, ,,
Plot 9 Minerals nitrate of soda	2·03	,, ,, ,, ,,
Plot 15 Minerals sulphate of ammonia in autumn .	5·03	,, ,, ,, ,,

It will thus be seen that the figures obtained by us at Nagpur are of the same order as those obtained at Rothamsted.

Leather[2] working on the drainage from the drain gauges at Pusa and Cawnpore occasionally obtained drainage containing over 30 parts per million of nitrate nitrogen. We do not consider, however, that the conditions in the field can be compared with those in drain gauges.

Summary.

1. The drainage waters are most concentrated in nitrates when they first begin to flow at the beginning of the rains. Thereafter their nitrate content shows in general a steady decrease throughout the rainy season. This confirms our work on nitrate content in soils (Part I) in which it was shown that the soil reached its maximum nitrate content early in the rains.

2. Soil which has been regularly irrigated in the dry seasons gives more regular drainage throughout the rainy season and the drains continue to run until later in the season than is the case on unirrigated soil.

GENERAL SUMMARY.

1. In the first part of the paper we have shown that when a soil is cropped with cotton or *juar* at Nagpur, nitrification is only active during the rains and mainly, in the early part of the rains. The maximum accumulation of nitrate, however takes place too early in the growth of the plant to be of much use to it. The subsequent heavy rains wash out large amounts of nitrate from the soil into the subsoil out of reach of the plant, so that at first sight nitrification is a wasteful process inasmuch as only a small amount of the nitrate produced is of use to the crop. Later in the stage of growth of the cotton or *juar* there is a shortage of nitrate in the soil as the rain has washed out the nitrate and the presence of the crop prevents efficient cultivation which might encourage nitrification. The cotton crop remains on the land till December and the *juar* crop till mid November and hence prevent early cold weather cultivation. It seems that only during the rains does nitrification normally take place in the Central Provinces soils which are under cotton or *juar* sown in the rains. If, however, the land is cropped with a cold weather crop

[1]The Book of the Rothamsted Experiments, 1919, Hall and Russell, p. 232.

[2]Records of Drainage in India, *Mem. Dept. Agri India*, Vol. II, No. 1, p. 62.

e.g., linseed, gram or wheat, it receives efficient cultivation at the close of the rains and then such soil accumulates large amounts of nitrates in the surface 6" and a lesser quantity in the next 6". Thus in the case of land which is cropped with cold weather crops we get nitrification at 2 periods, firstly early in the rains and secondly during the cultivation of the land immediately after the close of the rains and preparatory to sowing in November. We have not so far been able to undertake a study of the effect of interculture on nitrification, but it would appear that efficient hoeing between the rows of cotton or *juar* whenever possible during the rains and at the end of the rains should prove of great benefit to the crop by increasing the nitrate supplies available to the plant. Unfortunately, weather conditions frequently make this difficult and if the land is left too late the surface dries out and then cannot be efficiently cultivated.

2. On the black cotton soil at Nagpur it appears that the soil undergoes an annual loss of nitrate equivalent to approximately 160 lb. of nitrogen. This means that the surface soil would be completely depleted of nitrogen in less than 50 years. Actually, it is shown that the nitrogen content of the soil has suffered no loss during the past 25 years. It seems obvious, therefore, that the loss of nitrogen as nitrate is counterbalanced by the fixation of free nitrogen from the air.

3. The Central Provinces cotton grower is shown to be at an economic disadvantage to his rivals in other parts of the world. In Egypt cotton is grown under irrigation in the hot weather and the conditions are ideal for nitrification. Plentiful stores of nitrate are always present in the Egyptian cotton soils, many times as great as we find at Nagpur, and there is little, if any, need in Egypt for nitrogenous fertilisers. At Nagpur during the growth of the cotton crop nitrates are only produced in any quantity early in the rains at a time when the crop is not ready to use it. In the later stages of the plant's growth the soil is deficient in nitrate. It seems inevitable therefore that a lower yield of cotton should be obtained in the Central Provinces than in Egypt. This lower yield can in part be made good by top-dressings of active nitrogenous fertiliser, if applied at the right time. This right time would vary over the cotton tract, but would be as soon as there was the earliest reasonable chance of no further seriously heavy falls of rain. The question of the partial substitution of cotton by some other crop has been referred to in the paper and is also dealt with by Mr. ALLAN in a note at the end of this Memoir.

Certainly, a large increase in the growth of fodder crops in the Central Provinces is desirable. This would enable cattle to be better fed. They would then be more efficient for work and would produce better class cows. As long as fodder crops are neglected, very little hope can be entertained of raising the standard of agriculture in the Central Provinces.

The results indicate that efficient cultivation at the close of the rains provides sufficient nitrates for a more extended growth of cold weather crops.

NOTE BY R. G. ALLAN, M.A.,

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My experience and a study of rainfall figures over the last 40 years will show that though we may get rain in heavy and continuous quantity after the 15th to 20th August the majority of the heavy rains, the washers out of formed nitrates, occurs before that date. After the middle of August breaks are commoner and heavy downpours of extended character, if not absent, at any rate much less frequent. If I were asked to give odds on the probable effectiveness of an application of nitrate or ammonium sulphate after the 15th of August I would be inclined to place it at about 4 to 1 in favour of an advantage from such a dressing. This, I think, is borne out by the generally paying results of 8 loads manure with the crop and 10 lb. nitrogen as nitrate put on as a top-dressing in August, when the progress of the plant has been checked by the leaching out of nitrates in July. I therefore prefer the emphasis on the importance of the utilisation of such fertilisers at the right time, presumably when the odds are against subsequent heavy rain and as I suggest sometime in the second to third week of August depending on the local rainfall average distribution.

The use of a fertiliser should come as soon as a study of local rain distribution gives this reasonable chance. In Berar, for instance, I would put this date earlier than Nagpur.

It should be noted that the work has been carried out on the wettest part of the cotton tract.

Over the larger part of the Cotton tract the rainfall ranges between 20 and 30 inches, and presumably the longer breaks would allow of the fresh formation of nitrates and the absence of so much heavy rain would lead to less washing down below the root range and to a better chance for fertilisers.

I do not dispute the statement that our conditions are not those of Egypt and we are growing cotton on less favourable terms, but I do not think that the terms through the cotton tract of the Central Provinces and Berars are universally as bad as those under study. We have not the Egyptian or irrigated area conditions, therefore we are debarred from growing cottons of their quality, but to some extent at any rate we counter that by growing a hardier and possibly a less exacting cotton, for which even if coarser, there is normally some definite market demand.

The paper shows (*a*) that generally through the cotton tract in the absence of the formation of nitrates on the scale recorded in Egypt, our cotton is grown on less favourable terms, and that yields can only be brought up by the judicious use of fertilisers (which makes our cost higher) and (*b*) that specially in the wetter tracts to the East and on possibly the lower lying fields elsewhere, where the natural re-

ceipt is augmented by the flow from higher areas, cotton is being grown under such obviously defective nitrate conditions as to be unlikely to pay, except under boom conditions. I would note that the cultivator realises this. About half the area under cotton in the Nagpur District is purely the result of a boom and will go back to *rabi* or *juari* with the end of the boom as it has done so more than once in past history.

There are, however, wide areas on which cotton can be economically grown, with normally assured profit, possibly on $3\frac{1}{2}$ million acres out of the 5 million to which the crop has been pushed by recent prices.

Groundnut is the most hopeful substitute as a commercial crop to replace cotton. It will, however, do best in the conditions where cotton is likely to be remunerative, *i.e.*, on well drained areas, where the rainfall is not too heavy, though on the experience of the past year it can, provided drainage is fair, stand more rain than cotton.

In the wetter tracts, either climatic or soil, an extension of *rabi* is possible, but over large areas of the cotton tract, the nature of the rains of the past 20 years makes the growth of *rabi* crops less safe than *kharif*.

CONTENTS

DIGESTIBILITY TRIALS ON INDIAN FEEDING STUFFS, III.

SOME PUNJAB HAYS.

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The composition and nutritive values of Indian cultivated fodders have received little attention from the skilled investigator in the past and still less attention has been given to the grasses of ordinary grazing pastures and the hays produced therefrom.

Our knowledge of what constitutes a satisfactory ration for animals whether for maintenance or for work or milk production, although still meagre and unsatisfactory, has nevertheless made rapid strides during recent years, and we are now compelled to regard a suitable ration, not as so much bulk weight of material to be given to an animal, and consisting of so much fat, carbohydrate and protein together with a certain amount of "salt" computed on somewhat arbitrary grounds, but rather as a finely adjusted mixture both quantitatively and qualitatively of those food elements which are known to be necessary for an animal's well being. Too little attention has been given in the past to the qualitative aspect of nutritional problems, and while it may be quite possible for an animal to be receiving an adequate quantity as far as bulk is concerned, and even as far as total "calories" are concerned, yet if the quantities and quality of the fats, carbohydrates and proteins are not properly balanced, deleterious effects may be the result. Of equal importance is a knowledge of what mineral elements enter into the composition of the ration, for as Orr has pointed out in a Rowett Institute Bulletin "The Importance of Mineral matter in Nutrition," a proper admixture of minerals in their correct relative proportions is of fundamental importance in all dietaries and rations if a high level of health is to be maintained, and the absence or deficiency of certain mineral ingredients which have hitherto been entirely overlooked, such as manganese, magnesium, iron, chlorides, etc., may be responsible for rendering an otherwise satisfactory ration, quite unsatisfactory. Previously sodium chloride was considered to be the one essential "salt," and the necessity for some mineral adjunct

to ordinary rations for dairy cows was shown in the practice of providing "salt licks," but modern research has revealed the necessity for many others, and also that their relative proportions shall conform to certain standards. It has also revealed in this connection that deficiencies or absence of certain ingredients, even if only required in minute quantities, seriously interfere with the proper assimilation and utilisation of those which are present and also of the other food ingredients, with the result that the whole mechanism of the animal's body is thrown out of gear and disease in one form or another is the result. A notable case in point is the profound disturbance which results if the iodine content is deficient.

The poor condition and low milk yield of the cows of Bihar and Orissa is a reflection of phosphate deflection in the soils of that Province, and consequent phosphate deficiency in the fodders, with the result that bone formation is poor and a weak and puny animal is produced.

The hard material constituting the bone of an animal is very largely made up of calcium phosphate, so that unless an adequate supply of both calcium and phosphorus is provided in the ration, a strong and healthy bone cannot be formed, and bone matter once formed is by no means a fixed, dead and inert deposit, but rather a live structure which has a very intimate relationship with the rest of the organism ; so much so that when an undue strain is made on the animal, such as in heavy milk production or during the feeding of rations deficient in mineral content, the bone matter comes to the rescue, and itself supplies some of the necessary ingredients from its own mass, a proceeding which will obviously result in disastrous consequences if the strain or deficiency is prolonged.

The feeding trials on some Punjab hays, some account of which is given in this paper, were the outcome of discussions with the Military authorities in the Punjab on the poor condition into which it was noticed, army animals sank when brought up from the plains and fed on the hill grasses, a condition which sometimes necessitated sending them down again to the plain for grazing when surprisingly marked improvement set in.

It was not by any means easy to say off hand to what this might have been due, or to what particular dietary deficiency it might be attributed. It was, therefore, decided to investigate the feeding values of some plains and hill hays, from a complete analytical point of view, and also to carry out digestibility trials using these hays as sole ration, in order to determine whether they constituted maintenance rations.

With the kind co-operation of Lieutenant-Colonel Marriott of the Army Head Quarters (Military Grass Farms), 30 maunds of hay were collected from Jutogh in the Simla Hills, from Sialkot and from Jullundur in the plains and brought to Lyallpur, when they were submitted to a thorough chemical analysis and the mineral content also systematically determined.

Feeding trials with cows were also conducted in order to determine how far these grasses differed from one another in actual feeding value from the point of view of

a maintenance ration, and in order to determine what added concentrates were necessary to bring them to a maintenance ration for fully grown cows and heifers.

Chemical analysis of the hays.

Table I shows the analytical composition of these hays and also of oat hay grown at Lyallpur, for the sake of comparison. This latter proved by trial to constitute a maintenance ration for both heifers and fully grown cows, but of the three hays investigated, only that from Sialkot proved to be a maintenance ration for heifers and fully grown dry cows as revealed by the daily nitrogen balance; this will be discussed more fully later.

The chemical analysis indicates that the ash content of the Sialkot hay was considerably greater than that of the others, as was also the protein content.

The rest of the figures do not show any pronounced differences.

Details of the ash analysis.

The details of the ash analysis of the hays are given in Table II, which shows that the Sialkot hay is richest in total ash content. It contains about twice as much iron as do the other two, the aluminium and sulphur contents are higher, as are also the chlorides, the potassium and the sodium.

It would be rash to draw conclusions from one or two isolated trials, but the higher salt content in conjunction with the higher protein content may throw light on the greater suitability of the Sialkot hay as a ration, but here again caution must be exercised before condemning a hay or a locality, as much depends on the time of gathering the hay, and on the season, factors to which reference will be made later.

Nature of hays used.

1. *Jullundur hay.* This hay was originally collected from several different areas in 1925, and stacked, the experimental sample of 30 maunds being collected from the stacks in August 1926.

The grasses constituting the hay appeared to have passed the milk stage before stacking, having apparently been cut rather late in the season.

The composition of the hay was almost entirely *Andropogon Contortus* (Lin.).

2. *Sialkot hay.* This consisted mainly of Anjan grass (*Pennisctum Cenchroides*) from the 1925 season and was similarly taken from the stacks in 1926. This hay had obviously been cut at an earlier stage, and possessed many more inflorescences, a fact which may help to account for its higher nutritive value.

3. *Jutogh hay.* This sample mainly consisted of a mixture of 2 grasses, *viz.* (1) *Andropogon Monticola* Schullet, and (2) *Rottboellia Perforata* Roxb. and contained a considerable amount also of fine spiral spikes derived from the inflorescence of some other grasses which caused considerable annoyance to animals when fed and evidently detracted from the digestibility of the mixture.

It is interesting to record here that grass which is cut and stacked at a period of growth before the inflorescences have matured has a greater nutritive value than grass cut later, a practical point to be borne in mind in grazing animals and in preparing hay. This is also in conformity with the findings of the Cambridge School of Agriculture, where recent trials have revealed the fact that the young growing shoots of grasses are much richer in all the necessary nutrient ingredients and constitute a satisfactory maintenance ration, so that if the grass is continuously cut and not left till maturity a much more valuable fodder is obtained. There are practical difficulties in India in the way of continuous cutting, but where grazing is possible it is advisable to let animals eat the young grass as it grows, when the recurring young shoots supply a continuous and rich fodder.

Feeding trials.

The three hays were fed first to three year old heifers, which did not differ by more than a month or two in age, in consecutive periods as shown in Table III with intervening non-experimental periods, in order to determine whether they constituted maintenance rations. Two heifers whose weight and growth curves are shown in Fig. I. were taken for each feed.

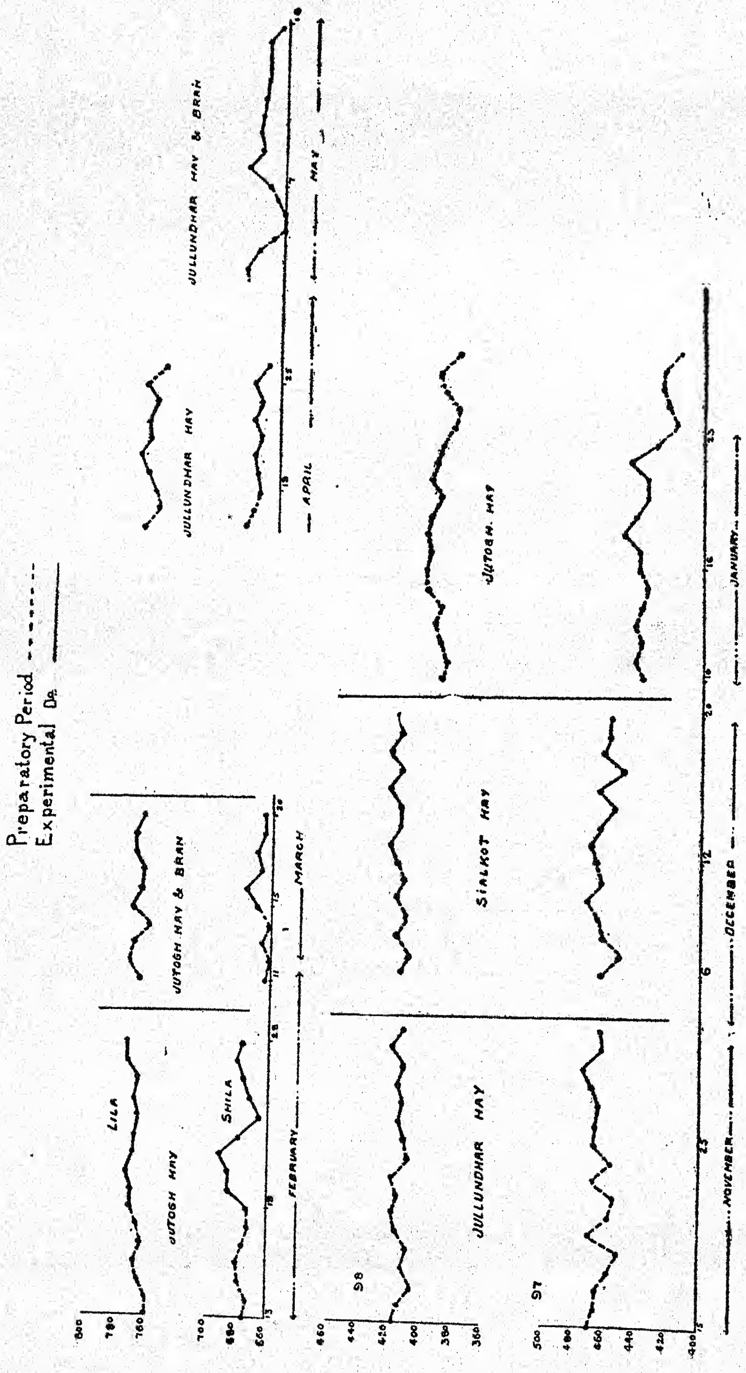

Fig. 1. Curves showing fluctuations in daily body weight of the cows.

This curve indicates that those heifers fed on the hill hay (Jutogh) lost weight while the others maintained theirs much better.

Each animal was separately weighed each morning between 8 and 9 A.M. and taken out for exercise for about 2 miles. On returning they were fed their morning ration with a salt lick, water being always available in a separate receptacle. The evening ration was fed between 4 and 5 P.M. In each case the hay was carefully chopped up and the residues collected the following morning. The urines and dungs were collected in the apparatus described by one of us (LAN ER) in Volume XXI, Part V, September 1926 of the *Agricultural Journal of India*.

In order to obviate errors in daily weighings and analysis, bags containing the daily feed for each animal were prepared and labelled for the daily ration at the commencement of the experiment. The daily residues from each animal were collected separately in labelled bags, and weighed at the end of the experimental period.

Table III shows the complete data obtained from the pair of heifers on the respective hays.

An examination of this Table, taken in conjunction with the table of analysis, reveals the following important facts:—

(1) The Sialkot hay is richer in ash and protein than the other two and gives a positive daily nitrogen balance as against a negative one for the others.

(2) The digestibility coefficient of the ration as a whole is greater in the Sialkot hay than in the others, and the digestibility coefficients of the protein of the Sialkot hay is almost double that of the others.

(3) The starch equivalent of the Sialkot hay as compared with the others is in the ratio of 3 : 2.

(4) The protein fed per day, the protein per 100 lb. of feed, and that digested, is much higher in the Sialkot hay.

(5) The albuminoid ratio of the Sialkot hay is narrower than that of the other in the proportion of roughly 1 : 2.

This experiment revealed the satisfactory nature of the Sialkot hay as a maintenance ration for growing heifers, and the deficiencies of the Jullundur and Jutogh hays. It was then thought advisable to see whether the different hays would prove to be maintenance rations for fully grown dry cows and in the event of their not being so to bring them up to maintenance standard by adding bran to the daily feed.

MAINTENANCE TRIALS WITH JUTOGH AND JULLUNDUR HAY ON FULLY GROWN COWS.

1. *Jutogh hay.* Two fully grown cows Shila and Lila seven years old, and weighing respectively 678 and 770 lb. were taken and fed on Jutogh hay alone for

ten days from 19th to 28th February, 1927, when it was found that the daily loss in nitrogen was 4·65 grm. and 5·91 grm. respectively, indicating that the hay did not constitute a maintenance ration. Wheat bran was now added to the feed in order to bring it up to maintenance standard.

From previous experiments the digestibility coefficient of wheat bran had been determined to be 23·16 using oat hay as a basal ration.

The digestible protein in bran had been found to be 9·83 lb. per 100 lb. of bran fed.

Jutogh hay and oat hay are roughages of similar type, although the analytical figures obtained in 1925 were slightly in favour of the oat hay. Assuming then that the efficiency of wheat bran fed with Jutogh hay to be same as when fed with oat hay, 1 lb. bran should add 7·13 grm. digestible nitrogen per day which would well cover the nitrogen deficient in the Jutogh hay.

Calculating on this basis, 0·65 lb. and 0·83 lb. bran when added to the Jutogh hay in the feeds for Shila and Lila respectively should be expected to bring the dietaries up to the maintenance level.

In order, however, to arrive at practical figures with a sufficient margin for individual error, the quantities of bran added to the Jutogh hay was 2·0 and 1 lb. respectively for the 2 cows, Shila and Lila. Thus Shila was getting more than the theoretical quantity and her diet should be well over a maintenance ration, while that of Lila would be nearer the margin between positive and negative. The animals were put on the experimental diet for 10 days before the actual experimental data were collected, the experimental period lasting 6 days only owing to the supply of hay running short.

The figures for the average daily nitrogen balance for the two cows worked out at +6·17 and —0·59 grm. nitrogen respectively.

In the case of Shila we thus find that when losing 4·65 grm. nitrogen per day on a Jutogh hay ration, the addition of 2 lb. bran per day converts this loss into a gain of 6·17 grm. nitrogen per day. Two lb. bran therefore represent a daily nitrogen retention of 4·65 *plus* 6·17 or 10·82 grm. nitrogen or 5·41 grm. per lb. of bran fed.

In the case of Lila who was losing 5·91 grm. nitrogen per day, the addition of 1 lb. bran per day does not quite suffice to bring the ration upto maintenance standard and she continues to lose 0·59 grm. nitrogen per day.

In this case, therefore, the addition of 1 lb. bran per day to the ration effects a nitrogen retention of 5·32 grm per day, which compares well with the figure 5·41 obtained for Shila.

From these two trials it may therefore be assumed that 1 lb. bran can repair a nitrogen deficiency to the extent of 5·4 grm. per day when Jutogh hay is fed *ad lib.* The daily average consumption of hay for the two cows Lila and Shila during the experimental period was 6·6 and 8·1 lb. respectively.

From these figures it is possible to calculate on a theoretical basis the exact quantities of bran that should be added to Jutogh hay in order to bring the cows

into nitrogen equilibrium. Shila who was losing 4·65 grm. nitrogen per day will need 0·86 lb. of bran and Lila, losing 5·91 grms. nitrogen per day, will need 1·11 lb. of bran.

The weights of two cows were 668 and 769 lb. respectively, so that a dry cow weighing from 600-800 lb. will need from 1 to 1¼ lb. of bran per day in addition to Jutogh hay of the composition shown when fed *ad lib.* The composition of the rations are shown in Table I and the details of the nitrogen figures in Table IV.

2. *Jullundur hay.* In order to obtain similar data from Jullundur hay, the same two animals were fed Jullundur hay alone *ad lib* from the 1st to the 18th April 1927, after which the experimental data were collected for one week, the same ration of course being continued. It was found that Shila weighing 675 lb. was losing 7·88 grm. nitrogen per day (the daily consumption of hay averaging 8·4 lb.), while Lila weighing 765 lb. was losing 8·25 grm. nitrogen per day.

Both cows were now put on Jullundur hay and bran for 13 days as a non-experimental period. Shila was given 2 lb. bran and Lila 1½ lb. per day.

Lila unfortunately fell sick, so the experiment was continued with Shila alone who, during the ensuing experimental period of 10 days, showed an average daily positive nitrogen balance of 3·25 grm. nitrogen.

Therefore 2 lb. of bran added per day to Jullundur hay represents an addition or retention of 7·88 *plus* 3·25 or 11·13 grm. of nitrogen per day, or one lb. of bran would furnish 5·56 grams of nitrogen retained per day.

From this it will be seen that 1·41 lb. bran should be added to the ration of Jullundur hay of the composition shown, fed *ad lib* to an animal weighing from 600-800 lb. in order to obtain a maintenance ration.

Summary.

1. Jutogh and Jullundur hays of the composition shown are not maintenance rations when fed *ad lib* either for heifers or fully grown cows.

2. For fully grown cows of from 600-800 lb. in weight Jutogh hay requires from 1 to 1¼ lb. of added bran per diem in order to effect a maintenance ration, whereas the Jullundur hay requires 1½ lb. of added bran.

3. The difference in nutritive value of the Sialkot hay on the one hand, and the Jullundur and Jutogh hays on the other, is apparently due to the former having been harvested in a younger condition. Considerable loss in nutritive value is incurred by allowing grass to grow beyond the early seed stage, or even as far as that stage.

4. The figures for the digestibility coefficients for growing heifers and full grown cows agree very closely indicating that as far as one can judge the digestibility does not depend to any great extent on age.

The figures for the digestibility coefficient of protein in both the Jullundur and Jutogh hays are low for the fully grown cows.

5. In determining such data as the above for added concentrates to different basal rations, some account must be taken for slight differences in composition of the basal ration. For example, in the case of Jutogh hay as basal ration, 1 lb. bran gives an added daily nitrogen retention of 5·37 grm., whereas using Jullundur hay as basal ration 1 lb. bran gives 5·56 grm. added nitrogen per day.

TABLE I.

Chemical composition.

	Moisture	Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract
	%	%	%	%	%	%	%
Jullundur hay	7·40	92·60	7·55	0·92	37·14	3·25	43·74
Jutogh hay.	6·44	93·56	6·86	1·31	36·84	3·50	45·05
Sialkot hay	9·28	90·72	9·15	0·88	35·06	4·38	41·25
Oats hay	3·36	96·64	6·53	1·84	33·94	5·69	48·64
Bran	8·17	91·83	4·97	3·54	11·19	12·75	59·38

TABLE II.

On 100 grams dry fodder.

Locality	Insoluble residue	P_2O_5	CaO	MgO	Fe_2O_3	Al_2O_3	SO_3	Mn_3O_4	Chlorides	K_2O	Na_2O
Jutogh . . .	4·216	·4173	·7957	·3539	·0775	·1613	·1091	·0104	2·475	1·304	·2178
Sialkot . . .	6·522	·4295	·5359	·1866	·1242	·1935	·3899	·0117	3·532	1·837	·3292
Jullundur . . .	4·507	·4138	·5651	·2199	·0591	·1174	·1011	·0133	3·034	1·552	·3044

TABLE III.

Growing heifers and dry cows.

Period	Name of cow	Average of daily body weight in lb.	Feed eaten daily in lb.		Per 100 lb. of food		Albuminoid ratio 1 :	Daily nitrogen balance in grams	Starch equivalent per day lb.	Protein per day lb.
					Starch equivalent lb.	Protein lb.				
25th November 1926 to 1st December 1926 (7 days).	97	467	Jullundur hay	6·9	22·42	1·02	42·2	—1·92	1·54	0·07
Ditto	98	413	Ditto	6·7	23·28	0·90	49·2	—3·91	1·56	0·06
12th December 1926 to 20th December 1926 (9 days).	97	462	Sialkot hay	9·3	35·77	2·15	22·1	+7·70	3·33	0·20
Ditto	98	418	Ditto	9·6	31·57	2·19	22·7	+7·75	3·03	0·21
16th January 1927 to 23rd January 1927 (8 days).	97	441	Jutogh hay	5·4	22·17	0·93	45·5	—4·55	1·20	0·05
Ditto	98	395	Ditto	5·3	20·87	0·76	53·8	—8·40	1·10	0·04
19th February 1927 to 28th February 1927 (10 days).	Lila	770	Ditto	6·4	22·27	0·47	92·3	—5·91	1·43	0·03
Ditto	Shila	678	Ditto	8·4	23·28	0·60	74·2	—4·65	1·96	0·05
15th March 1927 to 20th March 1927 (6 days).	Lila	769	Ditto Bran	6·6 1·0	..	..	24·6	—0·59	2·20	0·14
Ditto	Shila	668	Jutogh hay Bran	8·1 2·0	..	..	18·5	+6·17	3·50	0·27
19th April 1927 to 25th April 1927 (7 days).	Lila	765	Jullundur hay	6·8	23·89	0·59	76·0	—8·25	1·62	0·04
Ditto	Shila	675	Ditto	8·4	26·82	0·72	66·8	—7·88	2·25	0·06
7th May 1927 to 16th May 1927 (10 days).	Ditto	673	Ditto Bran	8·2 2·0	..	..	21·6	+3·25	3·06	0·22

TABLE III—(*continued*).

Growing heifers and dry cows.

Period	Digestibility coefficients						Nutrients digested per day in lb.					
	Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract	Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract
25th November 1926 to 1st December 1926 (7 days).	53·78	5·77	33·34	67·06	26·93	40·55	3·42	0·03	0·02	1·71	0·07	1·20
Ditto	47·67	..	33·87	62·25	23·08	46·72	2·96	..	0·02	1·55	0·06	1·35
12th December 1926 to 20th December 1926 (9 days).	58·04	30·58	37·51	66·26	48·79	57·57	4·95	0·26	0·03	2·16	0·20	2·21
Ditto	60·91	35·23	50·00	68·56	50·00	60·37	5·36	0·31	0·04	2·31	0·21	2·39
16th January 1927 to 23rd January 1927 (8 days).	44·88	2·78	50·00	58·03	25·00	43·70	2·23	0·01	0·05	1·12	0·05	1·04
Ditto	44·68	5·72	44·46	56·33	20·00	43·18	2·18	0·02	0·04	1·07	0·04	1·01
19th February 1927 to 28th February 1927 (10 days).	47·25	11·36	37·50	56·79	13·64	47·22	2·83	0·05	0·03	1·34	0·03	1·36
Ditto	48·23	8·62	27·28	58·06	17·24	48·69	3·79	0·05	0·03	1·80	0·05	1·84
15th March 1927 to 20th March 1927 (6 days).	49·87	4·00	46·15	56·70	38·90	52·25	3·54	0·02	0·06	1·44	0·14	1·86
Ditto	55·63	16·67	55·57	58·44	50·00	59·51	5·24	0·11	0·10	1·87	0·27	2·88
19th April 1927 to 25th April 1927 (7 days).	48·90	1·96	33·34	59·70	18·17	50·35	3·08	0·01	0·02	1·51	0·04	1·50
Ditto	52·84	9·53	37·51	64·78	22·23	52·33	4·11	0·06	0·03	2·02	0·06	1·92
7th May 1927 to 16th May 1927 (10 days).	51·77	5·56	60·00	57·20	41·51	56·08	4·88	0·04	0·09	1·87	0·22	2·68

Table IV.

Showing details of daily nitrogen balance in grams.

Name of cow	Feed	Intake		Output		Total intake	Total output	Balance
		Hay	Concentrates	Dung	Urine			
97 . . .	Jullundur hay .	19·17	..	13·50	7·59	19·17	21·09	—1·92
98 . . .	Ditto .	18·69	..	14·70	7·90	18·69	22·60	—3·91
97 . . .	Sialkot hay .	29·52	..	14·62	7·20	29·52	21·82	+7·70
98 . . .	Ditto .	30·47	..	15·06	7·66	30·47	22·72	+7·75
97 . . .	Jutogh hay .	14·78	..	10·98	8·35	14·78	19·33	—4·55
98 . . .	Ditto .	14·50	..	11·66	11·24	14·50	22·90	—8·40
Lila . .	Ditto .	16·25	..	13·50	8·66	16·25	22·16	—5·91
Shila . .	Ditto .	21·33	..	17·11	8·87	21·33	25·98	—4·65
Lila . .	Jutogh hay & bran .	16·76	9·25	15·76	10·84	26·01	26·60	—0·59
Shila . .	Ditto .	20·57	18·50	19·81	13·09	39·07	32·90	+6·17
Lila . .	Jullundur hay .	16·04	..	13·17	11·12	16·04	24·29	—8·25
Shila . .	Ditto .	19·81	..	14·97	12·72	19·81	27·69	—7·88
Shila . .	Jullundur hay & bran	19·33	18·5	22·40	12·18	37·83	34·58	+2·25

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THE DETERMINATION OF THE ELECTRICAL CONDUCTIVITY OF THE AQUEOUS EXTRACT OF SOIL AS A RAPID MEANS OF DETECTING ITS PROBABLE FERTILITY.

BY

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The electrical conductivity of aqueous extract of soils has been measured by many workers for various purposes but, with the exception of Joseph[1] and Atkins,[2] none has tried so far to correlate it with soil fertility. The former observes that, for samples from good and bad yielding plots of the Blue Nile soils taken from the same area and in the same season, there is a correlation between high electrical conductivity of the aqueous extract and low yield. Atkins, however, has attacked the problem from the biological point of view and he appears to have succeeded in showing that a measurement of the rate of change of the electrical conductivity of the aqueous extract as the extraction proceeds may be used to indicate soil fertility. His method was to place 10 grm. of air-dry soil in a bottle and add to it 50 c.c. of conductivity water, the mixture being shaken at intervals of 3 to 4 hours. After a certain period he centrifuged about 10 c.c. of the mixture and determined its electrical conductivity at 0°C. This determination he continued until such time when there was no further change in the values. His general conclusion was that although a high electrical conductivity in the extract may only indicate the presence of an excess of salts, a rapid increase in conductivity as extraction is prolonged indicates increased solubility, partly through bacterial action and may, therefore, be considered as a useful indication of fertility. A low conductivity, which remains low on continued extraction, denotes a soil of low fertility.

This suggestion of Atkins', provided it proved to be of general applicability, would furnish an extremely simple and easy means of measuring soil fertility. In order to test it thoroughly a number of soil types were obtained from different parts of India of which the relative cropping value was known, to determine, if possible, their relationship to measurements of the change in the electrical conductivity of their aqueous extracts as the extractions were prolonged. Each sample represented the top six inches of the soil, and after air drying was passed through a sieve of 80 meshes to the inch; particular care was taken to remove pieces of straw

[1] *Reports of the Sudan Government Chemist for the years* 1921, 1922, 1923, etc.
[2] *Jour. Agri. Sci.*, Vol. 14, p. 198, April 1924.

or other undecomposed plant residues. One part of this dry soil was then mixed with five parts by weight of conductivity water in a resistance glass tube closed at one end. The open end was then closed by means of a paraffined cork carrying a dip-electrode which dipped into the soil extract, and the whole sealed with paraffin in order to cut off all connection with the outside atmosphere. The cell constant had been determined by means of $\frac{N}{10}$ KCl solution previously. The apparatus was then placed in a thermostat maintained at 30°C., this being found to be the most convenient working temperature and the conductivity of the extract determined at different intervals of time using a metre-bridge and standard resistances. Before each measurement was taken with the exception of a few in Table II, the mixture of soil and water was shaken and then allowed to stand for two hours. It is to be noted that this shaking before each determination is necessary as otherwise misleading results might be obtained (as shown in Table II), and that, except in rare cases such as in heavy alkaline soils (Table I, Series VIB, Sample No. N Plot outside the Sukkur farm), the conductivity of the mixture of soil and water after standing for two hours compares closely with that of the clear extract obtained by centrifuging. The error thus introduced is negligible and does not interfere with the general conclusions.

Experimental Results.

In Table I, each of the Series I to V contains two samples of soil, one from a good field and the other from a neighbouring bad, almost barren field. Series VI (*a*) contains three samples of soil from fertile land, while Series VI (*b*) contains three samples from adjacent barren patches. The sixth column from left gives the conductivities of the extracts at 30°C. multiplied by 10^6 at the intervals of time, denoted in days by the figures in the brackets. Conductivity values not followed by any such figure in brackets were measured about three hours after the addition of water to dry soil.

TABLE I.

Series No.	Locality	Kind or type of soil	Soil sample No.	Manure used	Conductivity × 10^6 at different intervals	REMARKS
I	Cinchona camp, Mergui, Burma.	Acid	1	*Nil*	64(1), 75(3), 94(5), 131(7)	Collected from land where young cinchona plants were growing well.
	Ditto	Do.	2	*Nil*	72(1), 73(3), 72(5), 74(7)	Collected from land where young cinchona plants had died.
II	Burma.	Paddy	1	*Nil*	75(1), 111 (4), 163(9), 182(10)	Crop (paddy) yield—2,636 lbs. per acre. (1923-24).
	Ditto	Do.	2	*Nil*	62(1), 64(4), 82(9), 82(10)	Crop (paddy) yield—414 lbs. per acre. (1923-24).
						Yield in lb. — 1921 *aus* Paddy; 1922 *aus* Paddy; 1923 Mustard
III	N-Hazi Expt. plot, Dacca, Bengal.	Laterite	*b.*	Bone meal	48, 60(5), 84(7), 111(12)	Per acre — 1,168; 683; 63
	Ditto	Do.	*a*	*Nil*	41, 46(5), 47(7), 50(11)	Ditto — 400; 316; 10½
IV	N-Pangarbi Field, Pusa, Bihar.	Calcareous	3(*a*)	Farmyard manure	142, 194(2), 342(5), 402(7)	Collected from a place where oats grew thickly.
	Ditto	Do.	3(*b*)	Ditto	1080, 1103(2), 1135(5), 1153(7)	Collected from a barren patch near the above.
V	S-Pangarbi Field, Pusa, Bihar.	Do	5(*a*)	Ditto	108, 157(2), 235(5), 264(7)	Collected from under thick stand of oats.
	Ditto	Do.	5(*b*)	Ditto	1038, 1056(2), 1067(5), 1077(7).	Collected from a barren patch near the above.
VI(*a*)	Sukkur Farm, Sind	Alkali	A6	Farmyard and green manure.	298(1), 410(5), 443(7)	Samples A6, B4, and B5, came from plots which originally consisted of bad sterile land but now thoroughly reclaimed giving high yields.
	Ditto	Do.	B4	Ditto	658(1), 818(5), 866(7)	
	Ditto	Do.	B5	Ditto	426, 466(1), 650(5), 740(9)	
VI(*b*)	Ditto	Do.	A4	Ditto	2700, 2745(2), 2750(4)	Samples A4 and A3 come from barren patches in reclaimed plots, while sample N from sterile land in the neighbourhood of the farm where no reclamation had been carried out.
	Ditto	Do.	A3	Ditto	28900, 28900(1), 28900(4)	
	Outside Sukkur Farm, Sind.	Do.	N	*Nil*	56900, 55950(3), 55950(5)	

The necessity for shaking the mixture of soil and water prior to a measurement, already mentioned, is illustrated in Table II. Up to the ninth day the test tubes were left undisturbed and it will be noted that the values of the conductivity remained sensibly constant for both soils over the period. In the remaining three determinations the mixtures were shaken and then allowed to stand for two hours before the conductivities were measured. There was an appreciable rise in the conductivity of the fertile soil but not in the unfertile soil. It is fair to assume if shaking had been carried out before the earlier determinations, the appreciable increase in conductivity shown for the fertile soil in the top line of Table II would have been secured at a correspondingly earlier period.

Cinchona Cultivation.

Samples in this table were collected from another part of the cinchona cultivation mentioned under Series I in Table I, were young cinchona plants also found to die away in some plots and thrive in others.

Table II.

Acid soil—Burma.

Soil sample.	P_H	Conductivity $\times 10^6$ at different intervals	Remarks
III	4·71	58(1), 58(2), 61(3), 62(4), 66(7), 72(9), 173(21) 248(23), 314 (25).	Collected from unmanured field where cinchona plants grew well.
II	4·67	64(1), 59(2), 59(3), 59(4), 60(7), 60(9), 62(21), 62(23), 62(25).	Collected from unmanured field where cinchona plants died.

The results in Table III are for two soils very similar to each other except that one receives superphosphate while the other does not.

Table III

Acid soil—Toklai, Assam.

Bhorbhetta—Kharikatia Plots.

Soil series	PH	Manuring	Conductivity × 10^6 at different intervals	Total crop (Tea leaf) in lb. per acre.		Content of phosphate as P_2O_5.	
				in 1922	in 1923	Total per cent.	Available per cent.
9	4·2	*Nil.*	71, 73(2), 79(7), 80(11)	1,567	1,839	·0352	·0023
12	4·25	Superphosphate	64, 69(2), 75(7), 77(11)	1,735	2,079	·0414	·0051

In Table IV, each series contains samples from two adjacent plots one of which yields more crop than the other. The seventh column from the left shows the approximate total increase in conductivity; the next column gives the average daily rate of increase for the whole period under examination.

TABLE IV

Series No.	Locality	Kind or type of soil	Sample No.	Manure used	Conductivity × 10^6 of extracts at different intervals	Increase in conductivity.	Average rate of increase per day	REMARKS
VII	H. J. Field, Pusa, Bihar	Calcareous	6(*a*)	Farmyard manure	240, 359(2), 640(24)	400	17	Both samples came from same plot: 6(*a*) from thick stand of oats, 6(*b*) from thinner stand.
	Ditto	Do.	6(*b*)	Ditto	211, 250(2), 346(24)	135	6	
VIII	C. M. Expt. plot, Dacca, Bengal.	Laterite	1	Green manure, lime and bonemeal.	85, 128(4), 167(7)	82	12	Crop Yield in lb. per acre — Jute 1,668, Paddy 1,482
	Ditto	Do.	10	*Nil*	37, 49(3), 78(8)	41	5	Jute 1,326, Paddy 711
IX	Karjat, Bombay	Paddy	(*a*)	*Nil*	890(1), 2900(5), 3680(7)	2,790	..	The plot (*a*) gives much higher yield than plot (*b*).
	Ditto	Do.	(*b*)	*Nil*	64(1), 136(5), 174(7)	110	..	
X	Madras	Dry Land	2(*a*)	*Nil*	183, 259(3), 336(7)	153	22	In all these series (X to XIII) the plots 2(*a*), 1(*a*), 5 and 3(*a*) give higher yields than the corresponding neighbouring fields. 2(*b*), 1(*b*), 1 and 3(*b*).
	Ditto	Do.	2(*b*)	*Nil*	132, 159(3), 226(7)	94	14	
XI	Madras	Wet Land	1(*a*)	*Nil*	203, 292(3), 450(7)	247	36	
	Ditto	Do.	1(*b*)	*Nil*	387, 484(3), 550(7)	163	24	
XII	Coimbatore, Madras	Calcareous	5	Complete manure N + K + P.	184, 403(5), 518(12)	334	28	
	Ditto	Do.	1	*Nil*	254, 419(5), 513(12)	259	22	
XIII	Madras	Garden Land	3(*a*)	*Nil*	244, 416(5), 533(7)	289	43	
	Ditto	Do.	3(*b*)	*Nil*	1215, 1410(5), 1435(7)	220	32	

Discussion of Results.

In each of the Series in Tables I and II, a very marked difference in the increase of electrical conductivity for soils of different cropping value can be noticed. For good soils in the majority of cases the conductivity rapidly increased to almost double the initial value in a week's time. On the other hand, the conductivity of the barren soils changed very little and in some cases remained remarkably constant.

Series I in Table I offers a typical interesting case. The chemical analyses of the two soils, and also their P_H values, are given below :—

—	Soil Sample I (P_H 4·84)		Soil Sample II (P_H 4·75)	
	Total	Available	Total	Available
	per cent.	per cent.	per cent.	per cent.
P_2O_5	0·0545	0·0037	0·0553	0·00256
K_2O	1·02	0·0093	0·8042	0·0146
N (organic)	0·176	..	0·146	..
Lime (as CaO)	0·058	..	0·078	..

All the percentages above are calculated on the dry weight of the soil.

It is apparent that from a chemical analysis of the two soils it is not possible to account for the wholesale death of cinchona plants in Soil No. II, and their thriving in Soil No. I. On the other hand, the rapid increase in the conductivity figures as the extraction is prolonged in the case of Soil No. I would seem to indicate the presence of a considerable proportion of available plant food and that the general conditions are more favourable for plant life. Conversely, the low conductivity figure for the bad plot, which remains remarkably constant on continued extraction, indicates, in Atkins' words, " a soil so insoluble as to render it unfertile."

The remaining series in Table I more or less confirm this view ; in some cases, however, such as the barren patches of Pusa and Sukkur Farm, high initial conductivity figures are obtained, indicating the presence of excess of salts and probably usar formation. But it is interesting to note, the conductivity values show that biological activities are considerably checked in such patches.

In the case of the soil outside the Sukkur Farm, (Series VI(*b*) N, Table I), the fall in the conductivity value instead of an increase may be attributed to settling of colloid particles, a considerable amount of which can reasonabiy be expected to exist in such a heavy alkaline soil. It is also possible that the shaking usually employed before each determination was not sufficient to spread them uniformly

throughout the extract. In such cases extracts should be centrifuged every time before each determination is made, but such soils are rare and one does not require a scientific test when a glance at the fields will reveal the cause of their infertility.

In Table III, samples from two adjacent plots, both growing tea plants, were taken, the one under Series 9 being unmanured, while the other under Series 12 was manured with Superphosphate. From an examination of the conductivity data of both the soils, a great difference between the yield of the two plots could not be expected. The figures for the yield for two consecutive years support the view and indicate that in these soils heavy application of phosphates will not correspondingly increase the yield.

In almost all the Series in Table IV, each of which contains two soils of somewhat different cropping value, the rate of increase in the electrical conductivity of aqueous extract of the good soil is greater than the corresponding rate of the inferior soil. It appears, therefore, that, with very few exceptions which can easily be explained, the conductivity determinations succeed in differentiating between soils of different fertility provided that the samples in any one series are taken from the same soil type. A direct comparison of the fertility of soils from widely differing formations would not of course be made on the basis of conductivity determinations alone, for obvious reasons; but within any given area, local variations appear to be faithfully reflected in corresponding changes in the conductivity data.

This result is particularly interesting as the experimental conditions of the conductivity measurements are analogous to the water-logged state in the actual field. However, it is well known that aerobic activities do proceed in such circumstances owing to the dissolved oxygen in the water, and the experimental results in this paper show that even in such conditions, oxidations and decomposition are quicker and greater in the more fertile soils.

Summary and Conclusion.

(1) A method is described for determining the changes in the electrical conductivity of soil extract as the extraction proceeds.

(2) The conclusions arrived at by Atkins are confirmed.

(3) The method is capable of accounting for failure to grow crops where a chemical analysis yields no indication.

(4) The method may also be suitably employed for an easy detection of comparative fertility of fields situated in the same locality.

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